UPPER ATMOSPHERE RESEARCH SATELLITE (UARS) MISSION

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GODDARD SPACE FLIGHT CENTER
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UPPER ATMOSPHERE RESEARCH

SATELLITE (UARS)

MISSION

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PREFACE

This document is being issued several years before launch of the Upper Atmosphere Research Satellite in order to provide interested people with a brief description of the scientific objectives and Investigations of the UARS Project.

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ACRONYMS

ACRIM	Active Cavity Radiometer Irradiance Monitor
AXIS	Atmosphere X-Ray Imaging Spectrometer
CDHF	Central Data Handling Facility
CLAES	Cryogenic Limb Array Etalon Spectrometer
DEC	Digital Equipment Corporation
D_2	Deuterium
FOV	Field of view
GCM	General circulation model
GSFC	Goddard Space Flight Center
HALOE	Halogen Occultation Experiment
HEPS	High Energy Particle Spectrometer
HRDI	High Resolution Doppler Imager
ISAMS	Improved Stratospheric and Mesospheric Sounder
ISTP	International Solar Terrestrial Program
MAG	Triaxial Magnetometer
MEPS	Medium Energy Particle Spectrometer
MIPS	Million instructions per second
MLS	Microwave Limb Sounder
MMS	Multimission Modular Spacecraft
NBS	National Bureau of Standards
nm	Nanometer
NonLTE	Non local-thermodynamic-equilibrium
PEM	Particle Environment Monitor
RAC	Remote Analysis Computer
RF	Radio frequency
SAMS	Stratospheric and Mesospheric Sounder
SBUV	Solar Backscattered Ultraviolet (Spectrometer)
SPAN	Space Plasma Analysis Network
SOLSTICE	Solar/Stellar Irradiance Comparison Experiment
SSPP	Solar/Stellar Positioning Platform
SUSIM	Solar Ultraviolet Irradiance Monitor
SWG	Science Working Group
TDRSS	Tracking and Data Relay Satellite System
UARS	Upper Atmosphere Research Satellite
UV	Ultraviolet
WINDII	Wind Imaging Interferometer

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1. <u>INTRODUCTION</u>

1.1 BACKGROUND

There has been increasing concern in recent years about the sensitivity of the Earth's atmosphere to external influences associated with natural phenomena and to changes arising from byproducts of various human activities. Long standing curiosity about atmospheric evolution and the factors influencing climate and weather has been sharpened and refocused by the discovery of technological threats that introduce the possibility of inadvertent atmospheric modification. Such changes, occurring both in the troposphere and the upper atmosphere (Figure 1-1), have far-reaching consequences for the terrestrial habitat, and may eventually set the basic constraints governing man's life on this planet. These potential threats, and other possible changes that may occur in the atmosphere, highlight the need for a long-term program of scientific research directed toward improving knowledge of the physical and chemical processes occurring in the Earth's atmosphere.

The Upper Atmosphere Research Satellite (UARS) is an important new mission aimed at improving our knowledge of the atmosphere above the troposphere, including the regions that are known to be especially susceptible to substantial change by external agents. The UARS will provide a focus for the resolution of scientific questions relating to the chemistry, dynamics, and overall energy balance of these regions, particularly with regard to the stratosphere and the mesosphere. Through a balance between measurements, theoretical studies of basic processes, and model analysis, it seems likely that substantial progress will be made in solving the outstanding physical and chemical problems of these regions. Extensive theoretical activity, coupled to data and model analysis, is an integral part of the program and has been since its inception.

1.2 GOALS

The goals of the UARS project are:

- To understand the mechanisms that control upper atmosphere structure and variability

- To understand the response of the upper atmosphere to natural and anthropogenic perturbations

- To define the role of the upper atmosphere in climate and climate variability

To accomplish these goals, several areas of scientific study are addressed by the program:

(1) Energy input and loss in the upper atmosphere

(2) Global photochemistry of the upper atmosphere

(3) Dynamics of the upper atmosphere
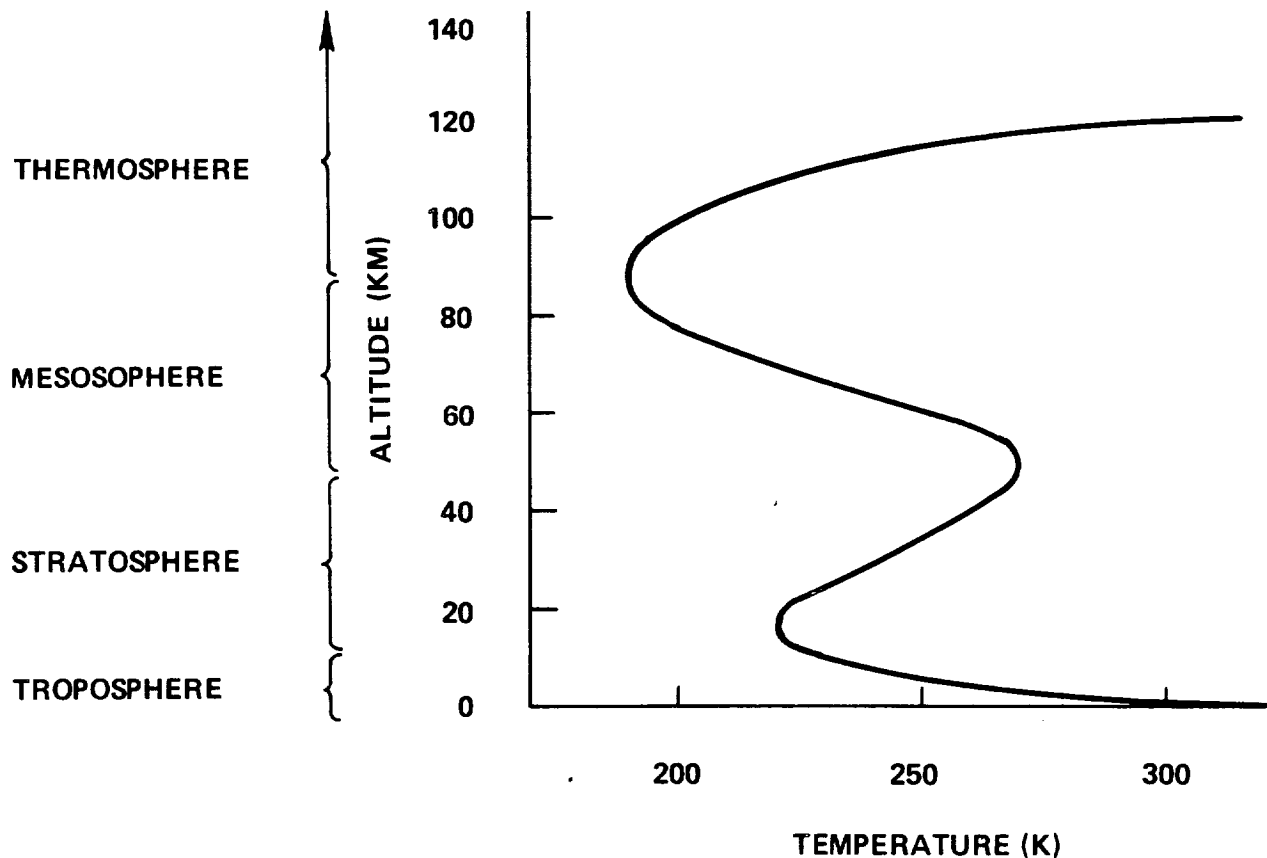
Figure 1-1. Regions of the Earth's atmosphere as defined by their temperature gradients with increasing altitude. The temperature maximum near 50 km, which gives rise to the stratosphere and mesosphere, is due to the absorption of solar-ultraviolet radiation by ozone.

(4) Coupling among processes

(5) Coupling between the upper and the lower atmosphere

The following paragraphs discuss these areas in more detail.

1.2.1 Energy Input and Loss

Virtually all of the solar irradiance in the spectral interval of 120 to 350 nanometers (nm) is absorbed in the stratosphere, mesosphere, and lower thermosphere. This energy, together with some magnetospheric energy inputs at high latitudes, is instrumental in the basic photochemical processes in the upper atmosphere. Solar irradiance, combined with cooling by emission in the thermal infrared, produces most of the seasonal, latitudinal, and vertical variability of the thermal structure, which in turn controls most of the dynamics of this region. Therefore, a quantitative understanding of the atmospheric radiative processes is essential to investigations of the dynamics and chemistry of the upper atmosphere.

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1.2.2 Photochemistry

In general, a qualitative understanding now exists of the sources, sinks, and budgets of most of the known upper atmospheric constituents. Study of the relevant chemistry can be divided into a discussion of a few families of constituents such as those containing nitrogen, hydrogen, and chlorine, and of the reactions between these families. There are three basic types of molecules within each of these families. The source molecules, which are relatively stable compounds, are usually evolved from biological, geological, or anthropogenic processes. Examples are N_2O, CH_3Cl, CCl_4, and CH_4. The radicals are short-lived derivatives of the source molecules which participate in rapid chemical reactions, such as the catalytic cycles of ozone (O_3) destruction. Examples are the simple oxides of N, H, and Cl, and the atoms themselves. Finally, the temporary reservoir/sink molecules are the more stable forms into which the radicals can be temporarily recombined and which may also be precursors to removal by heterogeneous reactions or "rainout." Examples of these are HCl, HNO_3, and $ClONO_2$. A more complete quantitative understanding of atmospheric photochemistry is essential to reliably predict effects of perturbations (e.g., due to halocarbons and fertilizers) on the upper atmosphere and assessment of the reliability of these predictions.

1.2.3 Dynamics

A great number of the constituents in the upper atmosphere have chemical lifetimes that are comparable to or longer than the time scales associated with transport phenomena. For these species, consideration of dynamics must accompany photochemical calculations to correctly explain observed constituent concentrations. Since chemical lifetimes depend on temperature and specie concentrations, these lifetimes are also altitude dependent. Perhaps the most striking example of the importance of dynamics in this regard is the observed high concentration of O_3 in the polar night stratosphere where photolytic processes are absent. Although transport of chemical constituents takes place in reponse to motions on a variety of time and length scales, global distributions of species are primarily influenced by planetary scale motions with periods of several days and longer. However, smaller scale motions are important in several contexts, of which the stratosphere-troposphere exchange of air is one example. It has been estimated that 70 percent of the total stratospheric mass is exchanged with the troposhere each year. Transport also acts to change the temperature (and consequently photochemical rate coefficients) during such processes as stratospheric warmings. The distribution of trace gases cannot be accurately calculated until these processes included.

1.2.4 Coupling Among Radiative, Dynamical, and Photochemical Processes

The energetics, chemistry, and dynamics of the upper atmosphere cannot be treated in isolation from each other, but must be viewed as highly coupled processes with both positive and negative feedbacks among them. Variability in ozone, induced photochemically by perturbations in chemically active trace species, will lead to variability in the distribution of radiative heating due to absorption and emission of radiation by ozone. This in turn will lead to variability in the temperature distribution. Since temperature and wind in the upper atmosphere are closely coupled (they both depend on the pressure distribution) temperature variability implies variability in the winds and hence in the transport of trace species. Such temperature and wind variability will generate changes

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in the ozone distribution due both to the temperature dependence of photochemistry and the re-distribution of various trace gases by the winds. The net effect of these couplings may be to either enhance or decrease the original ozone change. A full understanding of possible anthropogenic perturbations to the ozone layer requires that the energy sources and sinks, photochemical processes, and dynamical processes be treated as a coupled system for the global upper atmosphere.

1.2.5 Coupling Between the Upper Atmosphere and the Lower Atmosphere

In addition to the coupling processes previously mentioned, it is essential to consider the radiative, dynamical, and chemical coupling between the upper and the lower atmosphere. The budget of the ozone layer depends critically on the transfer of trace species between the troposphere and the stratosphere. The distribution and magnitude of such transfer is believed to be sensitive to variations in the tropospheric circulation. These variations, which may be associated with natural or anthropogenically induced climate variability, provide an important link between the problems of ozone change and climate change. An example of one aspect of this linkage is the role of water vapor. It is believed that the observed extreme aridity of the stratosphere is due to the "freeze drying" of air entering the stratosphere through the tropical tropopause. Any climate change that significantly altered the temperature of the tropical tropopause could substantially change the water budget of the upper atmosphere, with profound consequences for the photochemistry of the region.

In addition to the links provided between the troposphere and stratosphere due to radiatively active gases and to other chemical transport, there are dynamical links related to the vertical propagation of planetary scale meteorological waves. The behavior of these waves is sensitive to the distribution of mean winds in the upper atmosphere. Under some conditions it is believed that irregularities in the circulation of the upper atmosphere may cause anomalous reflection of such waves and thus significantly affect short term climate variability at the ground. Global observations of the upper atmosphere and its dynamical links to the troposphere and extensive theoretical work are required to definitively establish the role of the upper atmosphere in weather and climate. However, the fact that current forecast models which include the stratosphere provide better forecasts of the weather than do models which omit the stratosphere suggests that significant links exist.

2. MISSION CHARACTERISTICS

2.1 SCIENTIFIC MEASUREMENTS

The measurement requirements for the UARS mission and the scientific justification for those requirements were delineated by the UARS Science Working Group (SWG) and published in their final report (1978). In general, these requirements reflect the need for measurements of parameters related to the study areas of the previous section: energy inputs and vertical profiles of temperature, species concentrations, and winds. The SWG also defined the baseline requirements for the spatial and temporal extent and resolution of the measurements. To implement the scientific studies envisaged for the UARS, the measurements should be of a global nature and be essentially continuous in time. Given the characteristics of remote sensing from low orbiting satellites, this implies a global map every 24 hours. The data should also allow the detection of local (solar) time effects from the background of latitudinal and seasonal effects. The spatial resolution requirements are half a scale height in the vertical ($\sim$2.5 to 3 km) and 500 km latitude, while requirements on longitude resolution range from 1000 km to zonal means, depending on the specific study and the time scale of the measurement. The 500 km latitude resolution translates into about 1 minute time resolution along the satellite track, given the spacecraft velocity of 7.6 km/sec: this defines the basic requirement for the atmospheric sensors to be capable of making vertical profile measurements in 1 minute or less.

In September 1978, NASA issued an Announcement of Opportunity soliciting proposals for UARS investigations. Seventy-five proposals were received, of which 46 were for experimental investigations and 29 were for theoretical investigations. In 1981, the final complement of nine scientific instruments was chosen to best match the measurement capabilities to the previously defined measurement requirements. In recognition of the difficult and sophisticated task involved in deducing atmospheric parameters from the infrared spectrometer measurements, two investigators were identified to collaborate with these investigations in the area of data-processing algorithms. Ten theoretical investigators were chosen to participate in the UARS program to contribute in the areas of data analysis and interpretation and preflight planning. At the same time, two "instruments of opportunity" were added to the UARS complement to continue long-term measurements that were initiated on earlier programs. In 1984, one of these instruments, the solar backscattered ultraviolet (SBUV) sensor for ozone was deleted from the payload, because an identical instrument was designated to be flown in the same timeframe on an operational NOAA satellite. Data from the NOAA SBUV instrument, however, will be included as part of the UARS data base. An Investigator has been identified to be responsible for providing these data. Tables 2-1 through 2-6 list all the Principal Investigators, their institutions, and their contributions to the UARS.

The suite of remotely sensed atmospheric parameters, in conjunction with the instruments making the measurements and their respective altitude ranges, is shown in Figure 2-1. (The measurement redundancy seen in this diagram (e.g., for O_3 or NO) results from the selection of certain instruments to perform specific measurements, and the ability of those instruments to also make other measurements. For example, the microwave limb-sounder was chosen for its ability to detect ClO and H_2O_2 in the atmosphere, but it also measures O_3.) These sensors, along with the instruments sampling the solar electromagnetic and magnetospheric energy inputs, will provide the coordinated set of data needed to understand the mechanisms controlling upper atmospheric structure.

Table 2-1
UARS Energy Input Measurements

Instrument	Description and Primary Measurements	Investigator, Institution
SOLSTICE—Solar-Stellar Intercomparison Experiment	• Full disk solar irradiance spectrometer incorporating stellar comparison • Solar spectral irradiance: 115-440 nm	G. J. Rottman, University of Colorado
SUSIM—Solar Ultraviolet Spectral Irradiance Monitor	• Full disk solar irradiance spectrometer incorporating onboard calibration • Solar spectral irradiance: 120-400 nm	G. E. Brueckner, Naval Research Laboratory (NRL)
PEM—Particle Environment Monitor	• X-ray, proton, and electron spectrometers • *In situ* energetic electrons and protons; remote sensing of electron energy deposition	J. D. Winningham, Southwest Research Institute

Table 2-2
UARS Species and Temperature Measurements

Instrument	Description and Primary Measurements	Investigator, Institution
CLAES—Cryogenic Limb Array Etalon Spectrometer	• Solid-hydrogen cooled interferometer sensing atmospheric infrared emissions • T, CF_2Cl_2, $CFCl_3$, $ClONO_2$, CH_4, O_3, NO_2, N_2O, HNO_3, and H_2O	A. E. Roche, Lockheed Palo Alto Research Laboratory
ISAMS—Improved Stratospheric and Mesospheric Sounder	• Mechanically cooled radiometer sensing atmospheric infrared emissions • T, O_3, NO, NO_2, N_2O, HNO_3, H_2O, CH_4, and CO	F. W. Taylor, Oxford University
MLS—Microwave Limb Sounder	• Microwave radiometer sensing atmospheric emissions • ClO and H_2O_2	J. W. Waters, Jet Propulsion Laboratory (JPL)
HALOE—Halogen Occultation Experiment	• Gas filter/radiometer sensing sunlight occulted by the atmosphere • HF and HCl	J. M. Russell, NASA/ Langley Research Center (LaRC)

Table 2-3
UARS Wind Measurements

Instrument	Description and Primary Measurements	Investigator, Institution
HRDI—High Resolution Doppler Interferometer· WINDII—Wind Imaging Interferometer	• Fabry-Perot spectrometer sensing atmospheric emission and scattering • Two-component wind: 10-110 km • Michelson interferometer sensing atmospheric emission and scattering • Two-component wind: 80-110 km	P. B. Hays, University of Michigan G. G. Shepherd, York University, Canada

Table 2-4
Instrument of Opportunity

Instrument	Description and Primary Measurements	Scientist, Institution
ACRIM—Active Cavity Radiometer Irradiance Monitor	• Full disk solar irradiance radiometer • Continuation of solar constant measurements	R. C. Willson, Jet Propulsion Laboratory (JPL)

Table 2-5
Collaborative Investigators

| Instrument	Responsibility	Investigator, Institution
CLAES—Cryogenic Limb Array Etalon Spectrometer	Instrument science/algorithm development	J. C. Gille, National Center for Atmospheric Research (NCAR)
ISAMS—Improved Stratospheric and Mesospheric Sounder	Instrument science/algorithm development	J. M. Russell, NASA/ Langley Research Center (LaRC)
SBUV—Solar Backscattered Ultraviolet	Instrument science/data acquisition	J. E. Frederick, Goddard Space Flight Center (GSFC)

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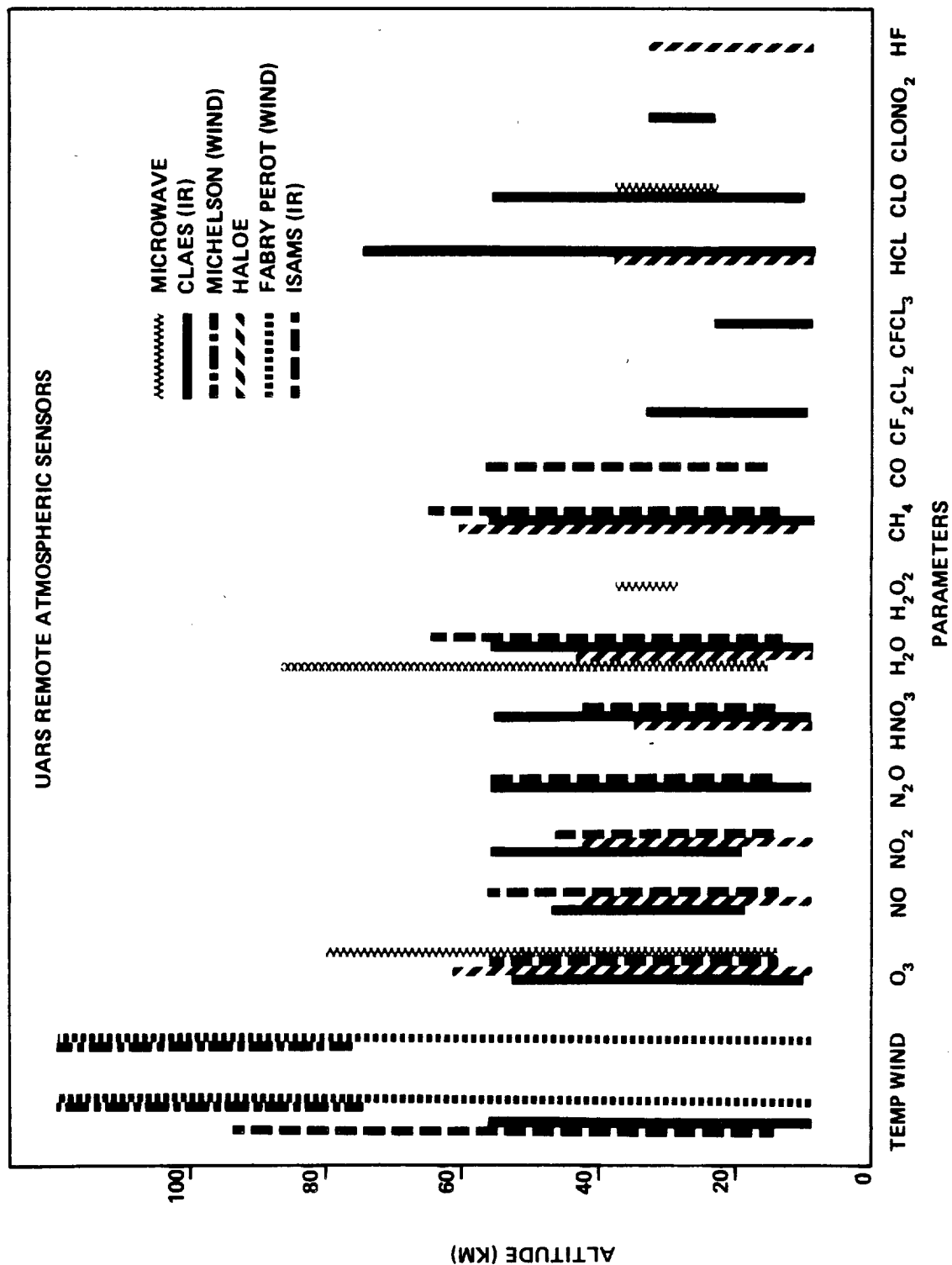
Figure 2-1. Altitude coverage of the atmospheric parameters measured by the UARS remote sensors

Table 2-6
Theoretical Investigations

Investigator	Institution	Investigation
D. Wuebbles	Lawrence Livermore National Laboratory	Chemical, radiative, and dynamic processes
D. M. Cunnold	Georgia Tech.	Impact of ozone change on dynamics
P. White	United Kingdom Meteorological Office	3-D stratospheric model
M. A. Geller	Goddard Space Flight Center	Dynamics
W. L. Grose	Langley Research Center	Transport, budgets, and energetics
J. R. Holton	University of Washington	Wave dynamics and transport
J. London	University of Colorado	Response to solar variations
A. J. Miller	National Oceanic and Atmospheric Administration	Meteorological interpretation
C. A. Reber	Goddard Space Flight Center	Analytic-empirical modelling
R. W. Zurek	Jet Propulsion Laboratory	Radiative-dynamic balance

2.2 LAUNCH AND ORBIT

The observatory will be launched in the fall of 1989 from the Kennedy Space Center using the NASA Space Transportation System (Shuttle). The Shuttle will deliver the spacecraft directly to the operational circular orbit at 600 km and inclined 57 degrees to the Equator. At this altitude and inclination the remote sensors "looking" 90 degrees to the spacecraft velocity vector can see to 80 degrees latitude, providing nearly global coverage. This inclination also produces a precession of the orbit plane such that all local solar times can be sampled in about 33 days, thus allowing resolution of diurnal atmospheric effects in a period which is short relative to seasonal effects. The planned operational lifetime for the mission is limited primarily by the 18-month lifetime of the solid cryogen used by the CLAES infrared instrument, and the observatory design lifetime is a minimum of 30 months. The fall launch, combined with the 18-month lifetime, will provide coverage of two Northern Hemisphere winters. (Northern Hemisphere winters were identified by the SWG as times and locations of particularly interesting atmospheric phenomena and they recommended enhanced coverage of these periods.)

2.3 OBSERVATORY

The UARS Observatory (Figures 2-2 and 2-3) will consist of the 10 scientific instruments, an instrument module including mission-unique equipment, and the Multimission Modular Spacecraft (MMS). The MMS will be used to provide attitude control, communications and data handling, electrical power storage and regulation, and propulsion. Mission-unique items include the solar array, a high-gain antenna for communication through the Tracking and Data Relay Satellite System (TDRSS), additional attitude sensors, and a solar/stellar pointing platform (SSPP).
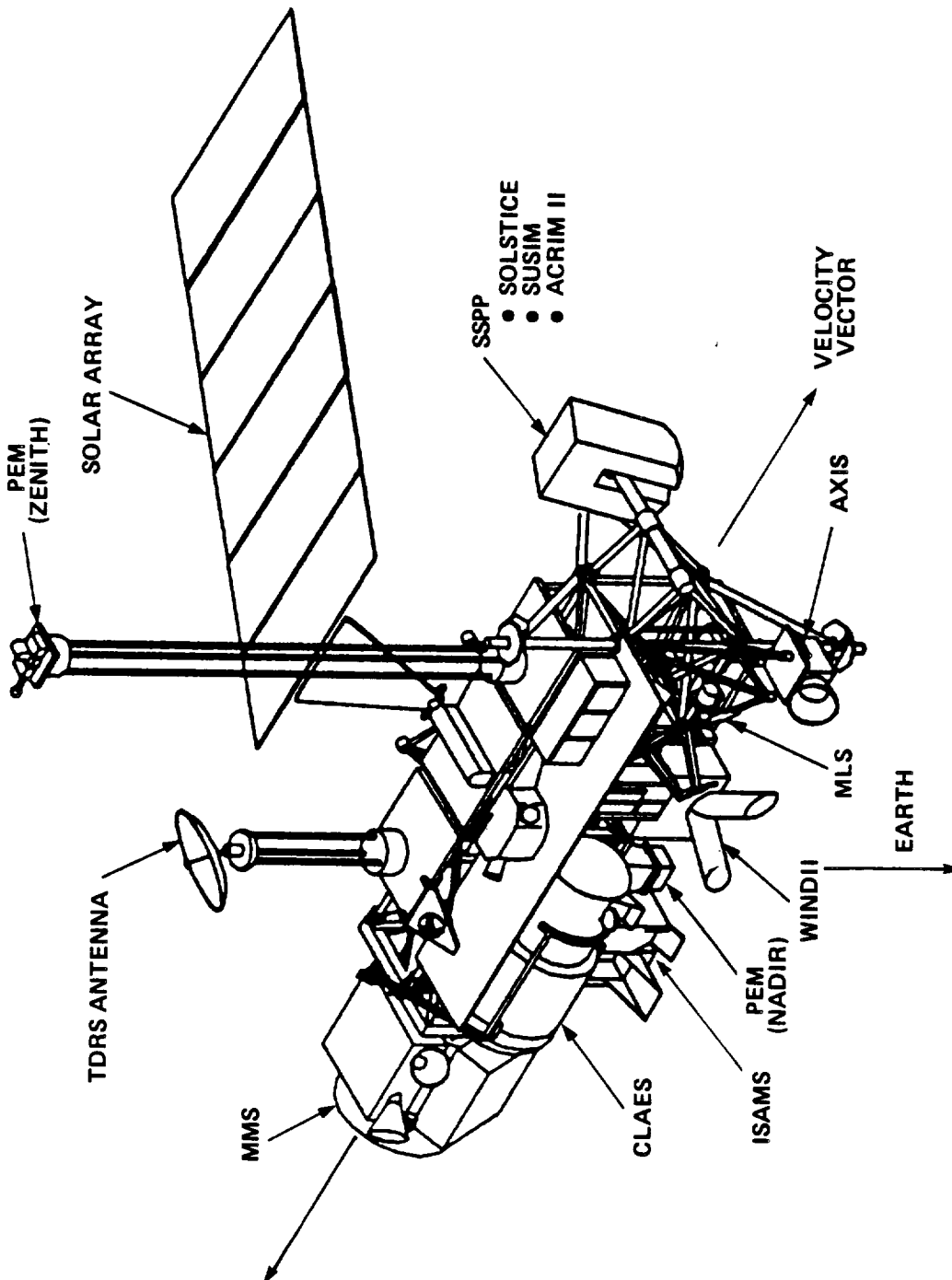
Figure 2-2. View of the UARS spacecraft from the antiSun side, showing instrument placement, solar array, and the Multimission Modular Spacecraft. Precession of the orbit plane with respect to the Earth-Sun line dictates a rotation of the spacecraft approximately every 33 days to ensure that sunlight does not impinge on certain instruments. Thus, the spacecraft will fly alternately "forward" and "backward" along the velocity vector. The HALOE and HRDI instruments can not be seen from this view.

UARS

10,000 LBS
170" DIAMETER
29' 2" HIGH

LANDSAT-D

3800 LBS
86" DIAMETER
18.5' HIGH

NIMBUS-7

2150 LBS
66" DIAMETER
12' HIGH

Figure 2-3. Size comparison (in launch configuration) of the UARS spacecraft with the Landsat-D and the Nimbus-7 spacecraft. The width of the UARS is essentially the same as that of the Shuttle bay.

The UARS instrument module structure will be designed to house the instruments and mission-unique equipment. The configuration will be designed to meet the combined fields of view requirements of instruments, solar array, attitude sensors, and the high-gain antenna. The thermal control desi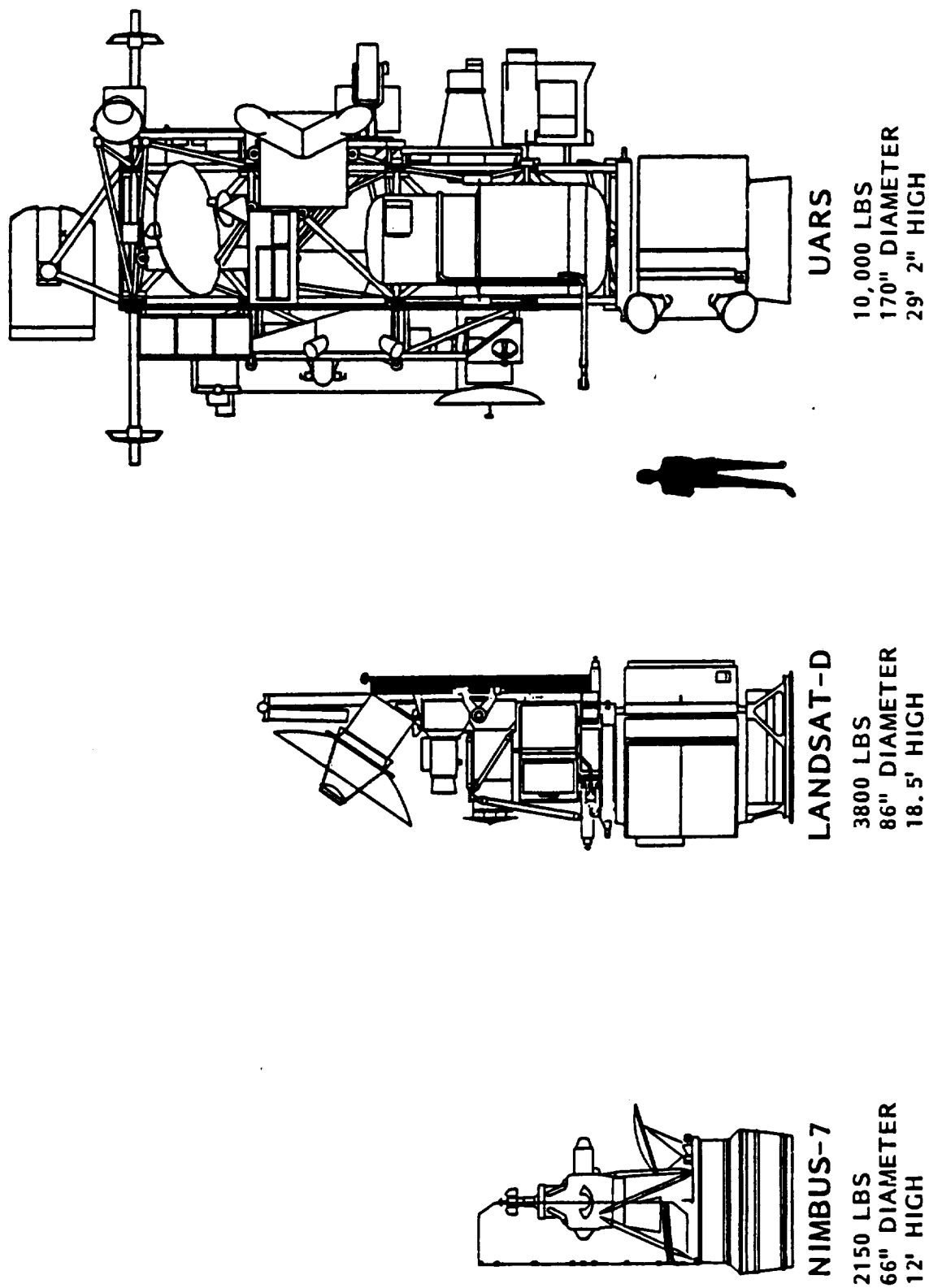gn will allow operation of any instrument at any duty cycle independent of the operational duty cycle of other instruments.

Two of the more important requirements on the observatory design are to provide Earth referenced control of instrument pointing to an accuracy of 0.1° and to include attitude sensors that can support ground determination of instrument boresight pointing to an accuracy of 0.03° (3σ).

The UARS power subsystem will consist of a solar array, the MMS Power Module, and power distribution electronics. The solar array will be sized to provide sufficient power for a period of 36 months.

Communications with UARS will be achieved through the TDRSS. Compatibility with TDRSS will be provided by a steerable high-gain antenna operating in conjunction with the MMS Communications and Data Handling Subsystem. This subsystem will also provide the command, telemetry, data storage, and computational functions. The UARS telemetry data rate will be 32 kbps with a tape recorder playback rate of 512 kbps.

The UARS design will include a hydrazine propulsion module which will have sufficient capacity to perform 180° yaw attitude maneuvers approximately every 33 days for the duration of the mission. These maneuvers will orient the observatory with respect to the Sun as needed to meet instrument thermal and viewing requirements. The propulsion system will also be used, if necessary, to maintain a nominal orbit altitude of 600 km.

2.4 DATA SYSTEM

The approach used for the UARS data system evolved from requirements defined by the SWG and subsequently refined by the UARS Project and Investigators. These requirements include:

- All scientific data received from the spacecraft should be processed as quickly as feasible to the level of geophysically useful data (e.g., atmospheric temperatures and gas species concentrations).

- The instrument Principal Investigators should be responsible for developing the algorithms and for implementing and maintaining the programs used for processing data from their instruments.

- All scientific data should be available in some form of on-line storage to all the Investigators.

- To minimize contention for computational resources, there should be functional separation between the computers used for data processing and storage and the computers used for the Investigators' scientific analyses.

Implementation of these requirements has led to a system comprised of a Central Data Handling Facility (CDHF) at Goddard Space Flight Center (GSFC), minicomputer based remote analysis computers (RAC's) at the investigators' sites, and a dedicated electronic communications system to connect the RAC's with the CDHF (Figure 2-4). Playback telemetry data from the observatory
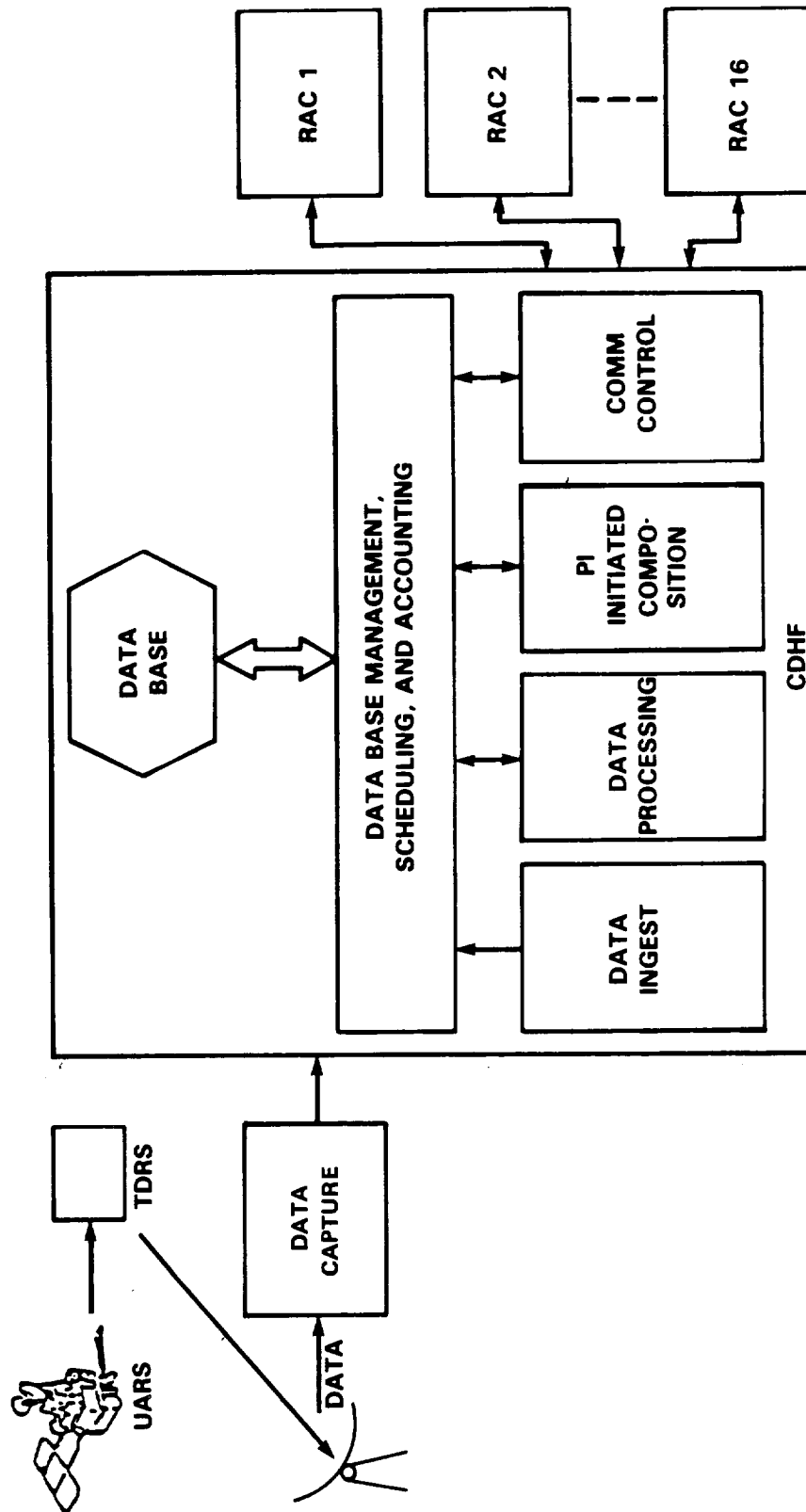
Figure 2-4. Block diagram of the UARS Central Data Handling Facility (CDHF) and the Remote Analysis Computers (RAC's)

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are relayed through the TDRSS to the Data Capture Facility at GSFC which performs quality checks, removes redundant data, reverses the data to time increasing order, and decommutates and formats the data for transmission to the CDHF. Here programs, developed by the investigators at their RAC's and transferred to the CDHF, will be used to convert telemetry data (referred to as level 0 data) to several levels of processed data.

Level 1 data are the physical parameters actually measured by the sensors (e.g., atmospheric radiances in the case of the limb sounding instruments). Level 2 data are the geophysical parameters calculated from level 1 data such as atmospheric temperature profiles, gas specie concentrations, winds, or solar-spectral irradiances. Atmospheric data at level 2 are related directly to the instrument measurement "footprint" (i.e., the character of the vertical scans is determined by a given instrument's scan rate, integration time, and viewing direction, and the spacecraft orbital trajectory). Level 3 data, on the other hand, reflect the geophysical information of level 2 transformed into a common format and equally spaced along the measurement trajectory in time (about 1-minute centers) and/or latitude (several degrees). Level 3 data will also contain latitude-longitude cross sections at approximately one-half scale height altitude intervals. The definitions of levels 1, 2, and 3 will be different from the above for those investigations determining energy inputs to the atmosphere. These investigations will define their data levels so that they are appropriate to the specific measurements being performed.

The CDHF will be used primarily for production processing of all scientific data received from the spacecraft, interactive processing of a small fraction of the data by the Principal Investigators from their RAC's to test algorithms, and maintenance of the UARS data base for access initially by the investigators and eventually by the scientific community at large. To support these activities, the CDHF will have a processing speed of at least 12 million instructions per second (MIPS) and at least 32 megabytes of real memory. Because the RAC's at the investigators' sites are based on Digital Equipment Corporation (DEC) VAX computers, the CDHF will use the DEC VMS operating system. Therefore programs written on the RAC's are fully transportable to and run directly on the central machine. In addition, there will be "virtual terminal" support, whereby a terminal at a RAC will appear to be signed on locally to the CDHF.

The various data sets that will reside in the CDHF data base include:

- All level 0 data

- The latest version of levels 1, 2, and 3 data

- Orbit and attitude data

- Solar and lunar ephemerides

- Correlative data

- System software, including the data catalog

- Data processing programs and associated data tables

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These data will be stored on line (e.g., on magnetic or optical disk) to facilitate quick access by users. A catalog of data maintained in a data base management system, will permit searches of characteristics such as measurement parameter, time, instrument, and data level.

The RAC's at the Investigators' sites will be used to access data in the CDHF, for geophysical analysis of these data, and in some cases for linking with larger computers for more complicated scientific analyses. For the Instrument Investigators and Collaborative Investigators, the RAC's will also be used to develop the software for processing data to levels 1, 2, and 3 in the CDHF. After launch, these Investigators will use their RAC's for data validation and refinement of their processing software. Another RAC function is the support of flight operations by interfacing with the command management system at GSFC for instrument command and control and microprocessor maintenance. The communications between the CDHF and the RAC's will use the DECnet protocol. This, in effect, creates a distributed data system for the UARS and facilitates connection with other scientific data networks such as the existing Space Plasma Analysis Network (SPAN) and the network to be used on the International Solar Terrestrial Program (ISTP).

2.5   DATA ANALYSIS AND THEORETICAL STUDIES

The UARS program, from its earliest planning phase, has included active participation by theoretical and analytical scientists representing all aspects of the study of the stratosphere and the mesosphere. Specialists in radiative transfer, atmospheric dynamics, and photochemistry lead theoretical groups as Principal Investigators on the UARS Science Team. In addition, many of the experimental investigations also bring Theoretical Co-Investigators to the Team. These scientists, who are involved in UARS-related research during the prelaunch phase, will provide important scientific support during the operational phase and will contribute heavily to the scientific interpretation of the measurements during the postflight analysis phase.

During the prelaunch phase, Theoretical Investigators are concerned with two major research areas:

a. Design of data analysis techniques—To optimize the estimation of geophysical fields such as temperature and ozone mixing-ratio for global synoptic mapping, techniques must be developed to interpolate in time and space from measurements made along the UARS orbital path. Tests of proposed techniques are being carried out using both previously acquired satellite data (e.g., from the Nimbus program) and synthetic global "data" sets produced by three dimensional global circulation models. The model data sets are sampled in a manner that simulates the measurement sampling by the UARS, and the ability of various analysis techniques to represent the true global distributions from the UARS data can be assessed. In particular, the influence of factors such as tidal variations and the spatial resolution and accuracy of the UARS data on the quality of the analyzed fields and the subsequent derived quantities can be tested by comparing the representations with the synthetic input "data."

b. Model development—Interpretation of UARS data will require a variety of theoretical models ranging from one dimensional radiative and photochemical models to three dimensional general circulation models (GCM's) with coupling among radiation, chemistry, and dynamics. Model development is a key part of the contribution of many Theoretical Investigators. During the prelaunch

phase most of the theoretical effort is devoted to model development that is designed to elucidate specific aspects of the science. For example, two dimensional (height-latitude) models are being developed that will have rather complete treatments of photochemical processes but simplified parameterizations of transport. Three-dimensional GCM's are being developed that have complete treatments of dynamics but simplified photochemistry. The eventual goal of this modeling effort is to develop a three-dimensional GCM that is capable of faithfully simulating the coupled radiative-dynamical-photochemical processes in the stratosphere and the mesosphere, and that can be used to predict the response of the ozone layer to anthropogenic influences.

During the flight phase, the Theoretical Investigators will collaborate with the Instrument Investigators in the analysis of data as these data are acquired by the instruments, and they will participate in planning observational strategies to optimize the scientific impact of the measurements. This collaboration will be particularly important for the planning of special observations in response to unusual events such as solar flares or sudden stratospheric warmings.

In the postflight phase, the investigators will conduct a variety of analyses and modeling studies using the entire UARS data set. The goal of these studies will be to elucidate as many aspects as possible of the structure, the chemistry, and the dynamics of the stratosphere and the mesosphere. Although individual investigators may emphasize radiative, photochemical, or dynamical aspects, the coupling among these processes will be a common theme. Therefore, the skills of the various investigators will be used in complimentary ways.

2.5.1 Specific Areas of Investigation

2.5.1.1 Responses to Radiative Inputs—UARS will provide accurate measurements of the spectrum of solar irradiance in the ultraviolet (UV) region where absorption by ozone provides the primary energy source for the stratosphere and the mesosphere. Because of the relatively small influence of atmospheric motions in the tropics near the stratopause ($\sim$50 km), the temperature and ozone distributions should be close to radiative and photochemical equilibrium. The responses of the ozone and the temperature fields in this region to variability in UV radiation measured by UARS will provide a sensitive test of the photochemical theory. Although UARS will not provide a record of UV variability over a complete sunspot cycle, variability associated with the 27 day solar rotation period and various other short period variations can be used to test whether the theoretically predicted correlated ozone and temperature responses occur.

2.5.1.2 Photochemistry of the Ozone Layer—UARS will measure the concentrations of a number of trace gases that are significant to the photochemistry of ozone. These measurements, combined with observations of temperature and UV radiation, will be used to test whether the observed distributions of various trace gases are in agreement with theoretical predictions. For example, observations of the distribution of chlorine monoxide (ClO) in the stratosphere will provide information essential to testing the theory that ozone is catalytically destroyed by chlorine in the stratosphere. In the upper stratosphere and the mesosphere, diurnal variability in the photochemistry must be accounted for. The gradual precession of the UARS orbit will permit sampling the composition at all local times over the course of about 1 month so that the validity of theories incorporating diurnal variations of photochemical processes can be tested.

2.5.1.3 Meteorological Analysis and Forecasting—Sophisticated data assimilation techniques, similar to the techniques used in operational weather forecasting, will be used to produce dynamically consistent fields based on UARS temperature and wind data. The UARS derived fields will be compared with operationally produced fields based on data from weather satellites; experiments will be conducted in short range forecasting—particularly in the event of a sudden stratospheric warming.

2.5.1.4 Diagnostic Data Analysis—Several groups will participate in analysis of the "climatology" using UARS global gridded data for the measured meteorological and trace species fields and various derived fields such as potential vorticity. Those studies will explore efficient representations for the temporal and spatial variability, consider the correlations among species and meteorological fields, and analyze the roles of mean and eddy components and their interactions.

2.5.1.5 Transport and Photochemistry—Three dimensional wind fields obtained from analysis of UARS data will be used for photochemical modeling in two different ways. In the first approach, the wind fields will be used as inputs to Eulerian models to compute photochemical budgets in either two or three dimensions. For two-dimensional models, wind data will be used to parameterize the transport terms and in three-dimensional models these data are included explicitly. In a second type of model, the UARS winds will be used to compute air parcel trajectories, and studies of the photochemical budgets will be carried out following material parcels. In both types of studies, UARS trace species data will be used to initialize and verify the models.

2.5.1.6 Mesospheric Dynamics—UARS will provide an opportunity to quantitatively examine the heat and momentum budgets of the mesosphere with the objective of elucidating the mechanisms for maintenance of the cold summer mesopause, the warm winter mesopause, and the strong semi-annual oscillation in ozone at the mesopause level. These studies will require accurate models of the heating near the mesopause, including non local-thermodynamic-equilibrium (nonLTE) radiative effects, and will also require estimates of the drag and diffusion caused by breaking gravity waves and tides.

2.5.1.7 Equatorial Dynamics—The direct wind measurements on UARS will provide a unique opportunity to obtain a climatology of equatorial waves such as Kelvin waves, and to define their roles in the driving of the observed semiannual wind oscillations at the equatorial stratopause and mesopause. Because of the weak temperature perturbations and small vertical scales of the equatorial waves, previous satellite experiments have been able to provide only limited information on equatorial dynamics, and wind observations will be particularly valuable for this region.

2.5.1.8 General Circulation Modeling—The improved understanding of radiative, dynamical, and chemical processes that UARS is expected to furnish will be used to aid in the development of global three-dimensional models by providing new insights into the important processes occurring in the upper atmosphere, and a global data set against which model output can be tested. With the development of the new generation of super computers, it should be possible, using the scientific advances supplied by the UARS, to develop a coupled radiative-dynamical-photochemical model that can faithfully simulate the meteorology and the chemistry of the stratosphere and the mesosphere. Development of this model is one of the primary goals of the UARS theoretical investigations.

3. <u>INSTRUMENTAL INVESTIGATIONS</u>

3.1 ENERGY INPUT

- Solar Ultraviolet Spectral Irradiance Monitor, G. E. Brueckner, Naval Research Laboratory

- Solar/Stellar Irradiance Comparison Experiment, G. J. Rottman, University of Colorado

- Particle Environment Monitor, J. D. Winningham, Southwest Research Institute

SOLAR ULTRAVIOLET SPECTRAL IRRADIANCE MONITOR (SUSIM)

G. E. Brueckner
Naval Research Laboratory

INTRODUCTION

Many different layers of the solar atmosphere from the photosphere, the temperature minimum layer, the chromosphere, and the transition zone emit radiation in the 120- to 400-nm wavelength band. Similarly, this radiation is absorbed over a wide altitude range (0 to 130 km) in the terrestrial atmosphere. An accurate knowledge of the Sun's output and its variability in this wavelength range is necessary to test models of the high atmosphere.

Measurements made to date in this wavelength range have established absolute solar fluxes within ±30 percent in the 140- to 210-nm region, with better accuracy at longer wavelengths. These measurements, however, are not accurate enough to establish credible values for long-term (solar cycle) variations of the solar flux. The amplitude of these variations will cover several orders of magnitude from an indetectable 0.1 percent in the photospheric continuum at 400 nm to more than 100 percent in strong emission lines originating in the upper chromosphere and the transition zone.

The observations of the Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) experiment have a threefold general objective: (1) to improve the accuracy of knowledge of the absolute solar fluxes, (2) to provide a highly accurate traceability of solar fluxes to a variety of ultraviolet radiation standards to be able to establish long-term (solar cycle) variations, and (3) to measure the variability of solar fluxes during several different time periods ranging from flare-produced changes ($\sim$ hours) to the variability caused by solar rotation (27 days). Specifically, the main objective of the measurements is to establish solar ultraviolet fluxes and their changes over a solar activity cycle in the wavelength region 120 to 400 nm. Of particular interest is the variability of the solar continuum in the 170- to 210-nm region, which is absorbed in the Schumann-Runge bands of the Earth's atmosphere. The specific experiment tasks are:

    a. To improve the absolute accuracy of solar continuum irradiance measurements in the 120- to 400-nm region with a goal of ±6 to 10 percent (wavelength dependent).

    b. To measure with high accuracy the intensities of the continuum below 208 nm relative to the intensities of the continuum above 208 nm with a goal of ±1 percent.

    c. To perform high-accuracy measurements of the intensities of solar emission lines relative to the stable solar continuum above 208 nm with a goal of ±1 to 5 percent (wavelength dependent).

    d. To improve the absolute accuracy of solar emission line irradiance measurements in the 120- to 400-nm region with a goal of ±6 to 10 percent (wavelength dependent).

Ultraviolet intensity measurements are particularly difficult because the solar radiation which is to be measured with high precision, at the same time is the main cause of instrument degradation. Therefore, in order to achieve the above mentioned goals, a new approach will be used with the main emphasis on improvements in four different areas: (1) improvement of existing calibration

methods, (2) a new scheme of a strict environmental control of the instrument, (3) elaborate combination of in-flight calibration and redundant measuring methods to distinguish instrument changes from true solar flux variations, and (4) cross-calibration of the long duration SUSIM on UARS by its sister instrument flown for short periods on Space Shuttle missions.

INSTRUMENT

The SUSIM, shown in block diagram form in Figure 1, consists of two identical double-dispersion scanning spectrometers, seven detectors (five photodiodes and two photon counters), and a set of ultraviolet calibration light sources.

One spectrometer is used daily to measure the time variations of the solar ultraviolet flux. The second spectrometer is used to track output changes of the calibration lamps.

Four deuterium (D_2) lamps, calibrated in spectral irradiance by the National Bureau of Standards (NBS), are used as the transfer standard source for in-flight calibration and stability tracking.

A spectral resolution of 0.15 nm over the entire wavelength range is obtained with two photon counters (operating in the stable pulse height discrimination mode), and 1- and 5-nm resolution is obtained with the five photodiodes (calibrated as transfer standard detectors by NBS). A microprocessor controls all instrument functions via program instruction.

The observational modes of the experiment include a continuous monitoring mode in which eight broadband channels (5-nm resolution) will be monitored several times daily. The channels are chosen to monitor the Lyman-alpha line at 121.6 nm and seven segments of the solar continuum, ranging from 145 to 390 nm. This mode is designed to measure the slowly varying component and continuum changes with high accuracy.

In spectral scan mode, which occurs once each day, the entire spectrum (120 to 400 nm) will be scanned with 0.1-nm resolution. This mode allows measurement of flux changes in all the emission lines caused by the slowly varying component. Also, once every day, a calibration and stability
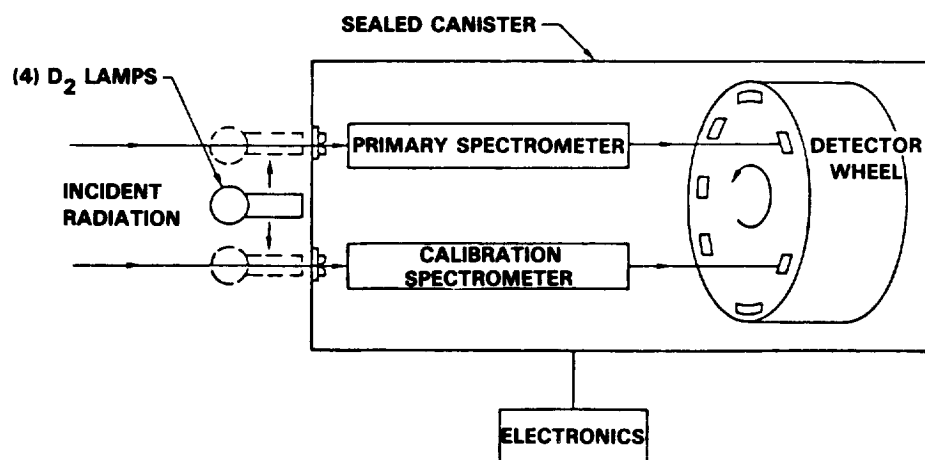

Figure 1. SUSIM Block Diagram

tracking measurement will be made using one of the three D$_2$ lamps. The aging of the prime D$_2$ lamp can be checked against the other three lamps which will be used on a weekly, monthly and annual basis, respectively.

The experiment will be mounted on the solar/stellar positioning platform. Instrument parameters are shown in Table 1.

Table 1
SUSIM Instrument Parameters

Type of measurement: Full disk solar spectral irradiance
Type of instrument: Double-dispersion scanning spectrometer
Geophysical parameters determined: Solar electromagnetic energy incident on atmosphere
Wavelength coverage: 120 to 400 nanometers (nm)
Comments: Onboard calibration to determine long-term sensitivity
Spectral resolution: 0.1, 1.0, and 5.0 nm
Instrument mass: 90.6 kg
Average power: 15 watts
Data rate: 2 kbps

CO-INVESTIGATORS

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SOLAR/STELLAR IRRADIANCE COMPARISON EXPERIMENT (SOLSTICE)

G. J. Rottman
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INTRODUCTION

The Solar/Stellar Irradiance Comparison Experiment (SOLSTICE) will measure the magnitude of the solar spectral irradiance in the wavelength range 115 to 430 nm with particular attention paid to the solar variability. Three basic time scales of solar variability are important: short term variations spanning time periods of minutes to hours and exemplified by solar flares; intermediate term variations lasting days to weeks and characterized by the solar rotation and the development of active regions; long term variations associated with the 11-year sunspot cycle or the 22-year magnetic field cycle. The SOLSTICE will have high relative accuracy and precision and will follow the short and intermediate term solar variations at and below the 1-percent level. Because of the limited lifetime of UARS relative to the solar cycle, it will be difficult to accurately infer long term solar variability. Comparison of the UARS measurements to irradiance data from other experiments made at different parts of the solar cycle is restricted due to the absolute accuracy of the respective measurements. Unfortunately, using present day calibration techniques such comparisons do not allow us to follow solar cycle variations smaller than 5 to 10 percent.

The unique feature of the SOLSTICE is its ability to accurately (± 1 percent) compare the solar irradiance with the ultraviolet flux of bright blue stars. These stars then become the standards against which the solar irradiance is measured. At all future times other instruments, perhaps similar but not necessarily identical to the SOLSTICE, can remeasure these solar/stellar ratios. The direct comparison of the future ratios to those obtained by UARS can be used to accurately infer the long term variability of our Sun. It would be remarkable to find that all blue stars are stable standards and do not vary with time; but by selecting 10 to 15 standard stars and by proper time series analyses of the ratios the true solar variation can be extracted.

INSTRUMENT

If a single spectrometer is to accurately compare the irradiance of the Sun to that of a star, it must use the same optical system: the same mirrors, the same gratings, and the same detectors. The SOLSTICE accommodates the seven to eight orders of magnitude difference between the solar and stellar flux in three ways. First a solar data point (10^4 counts) is obtained in less than 1 second and stellar measurement may take as long as 10^3 seconds. Second, the solar data are taken with a bandpass of 0.1 nm and the stellar continuum can be measured with a bandpass of 5 nm. Finally, the entrance slit for the strong solar signal is $<10^{-4}$ cm^2, compared to a stellar aperture of 1 cm^2. If we make use of all three of the above scaling factors, we can accommodate a signal difference as large as nine orders of magnitude.

The SOLSTICE consists of a single instrument mounted to the solar/stellar positioning platform of the UARS. Figure 1 is a cutaway view of the instrument. The spectrometer includes three separate spectral channels, each with a separate grating and photomultiplier tube detector to cover the full
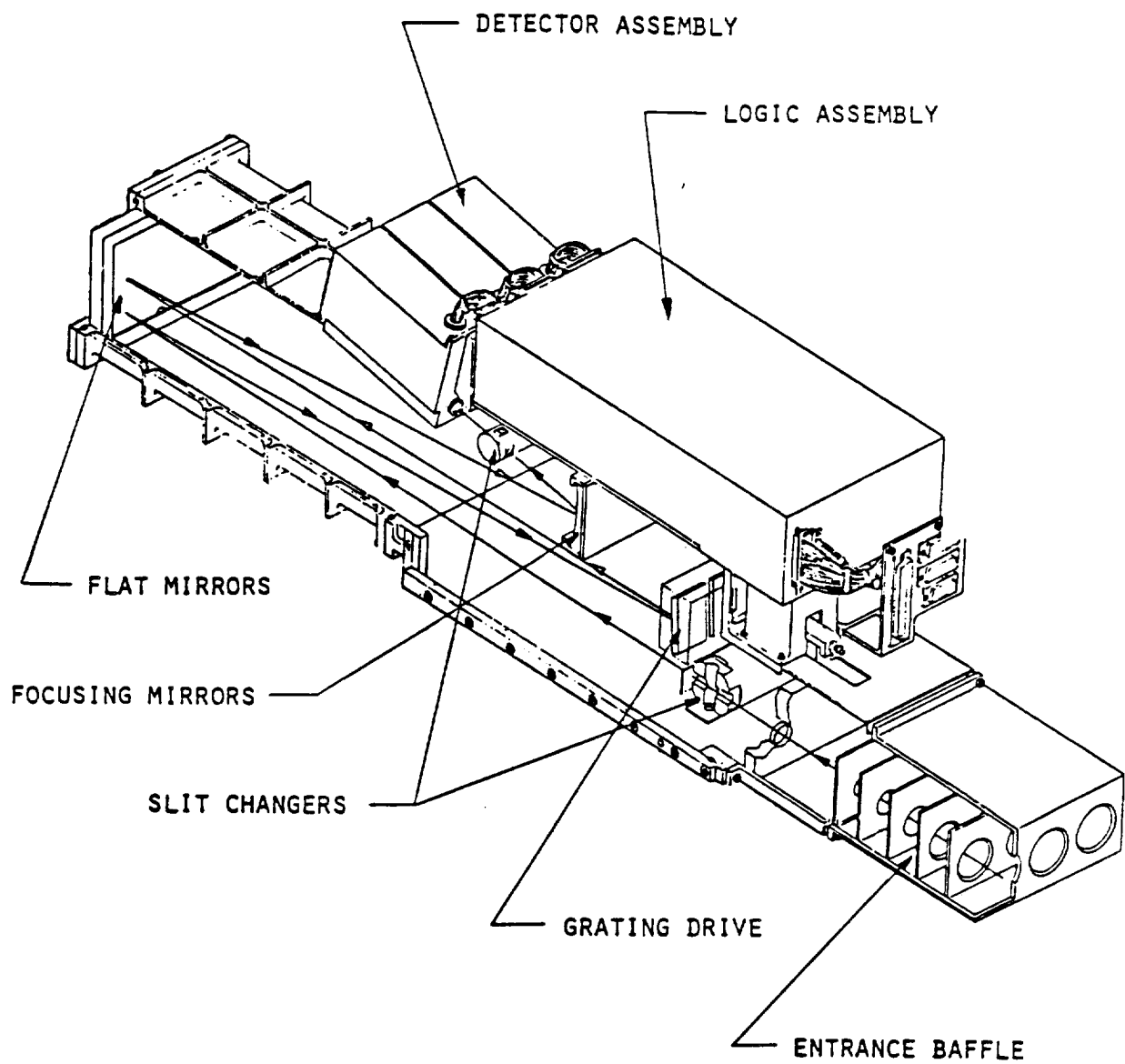
DETECTOR ASSEMBLY

LOGIC ASSEMBLY

FLAT MIRRORS

FOCUSING MIRRORS

SLIT CHANGERS

GRATING DRIVE

ENTRANCE BAFFLE

Figure 1. Solar/Stellar Irradiance Comparison Experiment (SOLSTICE)

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spectral range 115 to 430 nm. These three channels are stacked so that they share a common wavelength drive and entrance and exit slit interchange mechanism. A Sun tracker and star tracker are aligned to the SOLSTICE optic axis and are used to control the attitude of the UARS pointed platform. During the daylight portion of each orbit the Sun tracker will point the instrument to Sun center and the SOLSTICE will perform full wavelength scans of 2048 steps at a rate of one step per second. During the nighttime portion of most orbits, the SOLSTICE will be reconfigured to use the stellar entrance and exit slits and the platform will be pointed to one of the selected calibration stars. The instrument will be in a fixed wavelength mode and accumulate stellar data for approximately 15 minutes. Instrument parameters are shown in Table 1.

Table 1
SOLSTICE Instrument Parameters

Type of measurement: Full disk solar spectral irradiance

Type of instrument: Three channel solar/stellar spectrometer

Geophysical parameters determined: Solar electromagnetic energy incident on atmosphere

Wavelength coverage: 115 to 430 nm

Comments: Utilizes comparison with set of UV stars for determination of long-term stability

Spectral resolution: Solar—0.12 and 0.25 nm
                     Stellar—5.0 and 10 nm

Instrument mass: 15.4 kg

Average power: 5 watts

Data rate: 250 bps

CO-INVESTIGATOR

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PARTICLE ENVIRONMENT MONITOR (PEM)

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INTRODUCTION

To achieve a thorough understanding of the Earth's middle and upper atmosphere, all natural and man-made influences must be assessed. It is known that naturally occurring precipitating particles are constantly penetrating into the upper atmosphere and at times can be a significant influence on stratospheric, mesospheric, and thermospheric chemistry. The purpose of the Particle Environment Monitor (PEM) is to provide an integrated instrumentation approach that details both local and global energy inputs into the Earth's atmosphere by charged particles.

The information obtained from PEM will be used to pursue six specific PEM objectives in support of the primary objective of determining the global atmospheric energy inputs. These six goals are:

- To determine the effects of energetic particles on stratospheric, mesospheric and thermospheric chemistry—Energetic particles precipitating into the atmosphere have a significant effect on the chemistry of the stratosphere, the mesosphere, and the thermosphere through the production and transport of odd nitrogen species.

- To determine ozone reduction induced by solar protons—Energetic protons reaching the polar ionosphere strongly affect the abundance of ozone through the production of molecular nitrogen.

- To identify sources of nitric oxide—Energetic particles in the form of galactic cosmic rays are a continuous source of nitric oxide, leading to possible ozone depletion in the stratosphere.

- To determine the effects of energetic particles on noctilucent cloud formation—Noctilucent clouds are a well known but poorly understood feature of the summer high-latitude mesopause region. These clouds, which may form a semipermanent thin layer over the summer polar cap, may have an appreciable influence on summer high-latitude insolation.

- To study the physics of the interaction of particle fluxes with the atmosphere—Energetic particles entering the ionosphere can produce high levels of ionization and can play a key role in the complex physics of this region.

- To investigate anomalous ionization produced by energetic electrons—Precipitating energetic electrons are thought to disturb significantly the ionization levels of the ionospheric D-region during and following magnetic disturbances.

INSTRUMENT

The PEM consists of four primary instrument subunits: the Medium Energy Particle Spectrometer (MEPS), the High Energy Particle Spectrometer (HEPS), the Atmosphere X-Ray Imaging Spectrometer (AXIS) and the Triaxial Magnetometer (MAG). MEPS and HEPS will provide direct *in-situ*

measurements of precipitating electrons in the energy range from 1 eV to 5 MeV and protons in the energy range 1 eV to 150 MeV. AXIS will provide global images and energy spectra of atmospheric X-rays produced by electron precipitation over the energy range 2 to 300 keV. MAG will provide a measure of the joule energy deposition. These combined measurements will be used to attain the primary PEM objective of determining the global input of charged-particle energy into the Earth's stratosphere, mesosphere, and thermosphere and the predicted atmospheric responses.

MEPS and HEPS will measure particle fluxes in the energy range within which significant influences on the atmsophere can occur. In order to cover this large energy range, electrons and protons between 1 eV and 30 keV will be measured by energy per unit charge electrostatic analyzers (MEPS). Higher energy electrons (30 keV to 5 MeV) and protons (0.1 to 150 MeV) will be sampled by solid state range energy telescopes (HEPS).

Both MEPS and HEPS will be required to measure weak midlatitude precipitating fluxes in the presence of significant background radiation from trapped particles, thus requiring discrimination against such fluxes. MEPS will accomplish this discrimination by passive low Z/high Z shielding and HEPS will use an active, anticoincidence scintillator in addition to passive shielding.

Multiple sampling angles over the upper and lower hemisphere will be required to evaluate precipitating fluxes. MEPS will use eight electrostatic analyzers in an angular array covering the region between the zenith and the nadir. The MEPS analyzers will share common electronics. HEPS will use eight telescopes oriented on the spacecraft such that the required angular coverage is achieved over the range of magnetic field declination and inclination encountered by UARS.

Particle measurements are local at one point in space. A complementary approach that yields wide spatial coverage of particle energy is the measurement of X-rays emitted and scattered upward from the slowing down of energetic electrons in the atmosphere. X-rays in the energy range of about 2 to 300 keV will be measured by AXIS to reconstruct electron spectra that extend to 1 MeV energy with sufficient accuracy to evaluate the ionizing chemical effects in the atmosphere. AXIS will use an array of 16 X-ray detectors, providing spatial coverage (imaging) and spectral information (32 channels each detector) to investigate, on a global basis, the influence of high energy particles.

AXIS consists of two identical units each containing eight telescopes comprised of a thin silicon and thicker Germanium solid-state sensors. Pulse height analysis of the output pulses from each of the sensor systems will provide the X-ray spectra. From the X-ray spectra the incident electron spectra can be derived. Each of the 16 telescopes will be mounted at different angles with respect to the nadir with their fields of view contiguous in order to obtain X-ray image as the spacecraft moves in the orbital plane. Active anticoincidence scintillators in conjunction with passive aluminum and tungsten shielding will be used in AXIS to discriminate against background radiation. Thermal radiators will be used for passive cooling of AXIS to lower noise and hence achieve low energy photon measurements. Instrument parameters are shown in Table 1.

MAG consists of a triaxial fluxgate magnetometer on a 1-meter boom extended horizontally from the upper boom supporting the upward looking particle sensors. An analog to digital (A/D) converter will digitize the data.

Table 1
PEM Instrument Parameters

Type of measurement: Magnetospheric energy input to atmosphere

Type of instrument: Electrons and protons—electrostatic analyzers
and solid state range energy telescopes

Electron energy deposition—X-ray imaging spectrometer

Magnetic field—vector magnetometer

Geophysical parameters determined: Electron—1 eV to 5 MeV
Protons—1 eV to 150 MeV
X-rays—2 keV to 300 keV
Magnetic field—±24 to +60,000 nT

Instrument mass: 84 kg

Average power: 74 watts

Data rate: 3.5 kbps

CO-INVESTIGATORS

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3.2 SPECIES AND TEMPERATURE

- Cryogenic Limb Array Etalon Spectrometer, A. E. Roche, Lockheed Palo Alto Research Laboratory

- Improved Stratospheric and Mesospheric Sounder, Dr. F. W. Taylor, Oxford University

- Microwave Limb Sounder, J. W. Waters, Jet Propulsion Laboratory

- Halogen Occultation Experiment, J. M. Russell III, Langley Research Center

CRYOGENIC LIMB ARRAY ETALON SPECTROMETER (CLAES)

A. E. Roche
Lockheed Palo Alto Research Laboratory

INTRODUCTION

The primary objective of the Cryogenic Limb Array Etalon Spectrometer (CLAES) experiment is to obtain global measurements of the concentrations of a series of stratospheric minor species which are of significant interest to the photochemistry of the stratosphere in general and the ozone layer in particular.

The species of interest include N_2O, NO, NO_2, and HNO_3 in the nitrogen family, and $CFCl_3$ (FC-11), CF_2Cl_2 (FC-12), HCl, ClO, and $ClONO_2$ in the chlorine family, in addition to O_3, H_2O, CH_4, and CO_2. This measurement set includes some of the more important source, radical, and reservoir species involved in the ozone layer chemical system. For example, tropospheric N_2O and the flourocarbons 11 and 12 are thought to be major sources of odd nitrogen and free chlorine in the stratosphere. After transport to the stratosphere, they photochemically react to produce the radical species NO, NO_2, and ClO which react catalytically to destroy ozone. The species HCl, HNO_3, and $ClONO_2$ on the other hand form temporary reservoirs and possible sinks for odd nitrogen and chlorine. Odd nitrogen, for example, may be removed by raining out soluble HNO_3 in the troposphere, and chlorine by rainout of soluble HCl.

The species H_2O and CH_4 play very important roles in ozone-hydrogen oxide chemistry, with CH_4 playing an additional role as a major remover of free chlorine from the atmosphere through production of HCl, followed by rainout. CO_2, as the primary infrared emitter, dominates the radiative cooling in the stratosphere and its increase (e.g., due to fossil fuel burning) has received attention in recent years because of concern with the greenhouse effect. It is also used to infer temperature and pressure profiles. As described below, CLAES directly measures atmospheric radiance and then infers neutral composition. The radiance field is important to energy input and loss studies, radiation budgets, and climatic modeling.

Scientific data will consist of vertical profiles of the concentrations of the above species and temperature over the altitude range 10 to 60 km, acquired with vertical resolution of 2.8 km, and at 65-sec intervals.

INSTRUMENT

As its name implies, the CLAES experiment involves the remote measurement of Earth limb emission spectra. Characteristic infrared vibration-rotation line spectra of the species of interest are measured simultaneously at 20 different limb altitudes in the 10- to 60-km range. The measured spectral radiances are then inverted through an iterative relaxation process to yield concentration and temperature at each of the altitude points or pressure heights.

The 50 km altitude coverage and 2.8 km footprint size are realized through the use of a linear array of 20 discrete detectors. Pointing and orientation of the array with respect to the limb vertical

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coordinate are provided by the three axis stabilized spacecraft, although CLAES is capable of internal adjustment of the vertical pointing by as much as 60 km. The image of the array is swept horizontally across the limb as the spacecraft orbits, to provide the geographical coverage previously described. The 65 sec sample interval referred to, which corresponds to a 500 km grid size, arises from the time required to execute a complete spectral scan for all species in a 3.5 to 12.7 micron wavelength range. Much smaller horizontal sampling intervals can be obtained on demand by restricting the spectral scan range and concentrating on fewer species.

A limb viewing emission experiment of the type being described here, requires high spectral resolution and high radiometric sensitivity to isolate and accurately measure weak emissions from trace species against intense backgrounds from abundant emitters such as CO_2, H_2O, and O_3. The telescope and optical system must also be capable of a high degree of out-of-field rejection. This is to ensure that the very intense hard Earth surface emission does not contaminate the lowest altitude detectors, which sample only a few tenths of a degree above the surface horizon. The optical system and detectors must all be cryogenically cooled to varying temperatures to supress thermal emission from instrument surfaces and to permit low noise detector operation at infrared wavelengths.

The major elements of the instrument designed to meet these requirements are shown in Figure 1. Basically it shows an 0.25 cm^{-1} bandwidth solid-etalon Fabry-Perot spectrometer, coupled with a reflective telescope and a solid state linear detector array. A solid hydrogen cryostat, sized for a 2 year lifetime cools the detectors to 11 K, the spectrometer to 20 K, and the telescope foreoptics to 110 K. The deployable aperture door is used to maintain system vacuum during ground hold and launch and is used on a nominal 3 day open and 3 day closed schedule to conserve cryogen during mission lifetime. The door also serves as a flooded aperture whole optics secondary standard calibration source. Instrument parameters are shown in Table 1.

The spectrometer consists primarily of an etalon paddlewheel that both selects and spectrally scans any one of four solid Fabry-Perot etalons, and a filter wheel that selects any one of eight interference filters. The etalons have their center wavelengths located approximately at 3.5, 6, 8, and 11 microns, and each one has an operating range of approximately ±10 percent of its center wavelength.

A given etalon is operated in conjunction with one or two interference filters which isolate a narrow (10 to 15 cm^{-1}) spectral interval within the etalon operational range. Each interval contains selected features of one or more of the species of interest, and a spectral scan of these features at 0.25 cm^{-1} resolution is then affected by a small angle scan of the etalon.

The 6-inch aperture Gregorian telescope utilizes very low scatter parabolic primary and secondary mirrors arranged in a "Z" configuration with baffles, field and aperture stops to maximize out-of-field rejection and stray light suppression. The vertical pointing adjustment referred to previously is provided by the commandable LAAM mirror indicated in Figure 1.

The detectors are discrete gallium doped silicon devices, which exHibit low noise and essentially background limited performance at the wavelengths and photon fluxes of interest to this experiment. All array detector signals are simultaneously sampled at an 8 Hz rate and scientific and engineering data are telemetered to ground at 3 kbps.

Redundant microprocessors provide on board experiment control with the facility for updating or reloading all control parameters and operational modes from the ground.

Figure 1. Cutaway View of CLAES Instrument.

OUTER VAPOR COOLED SHIELD

INNER VAPOR COOLED SHIELD

VACUUM SHELL

SOLID HYDROGEN TANK

PRIMARY TELESCOPE MIRROR

SECONDARY TELESCOPE MIRROR

PRIMARY BAFFLE

TUNING FORK

LAAM MIRROR

FORE BAFFLE

MAIN ENCLOSURE CAN

APERTURE DOOR
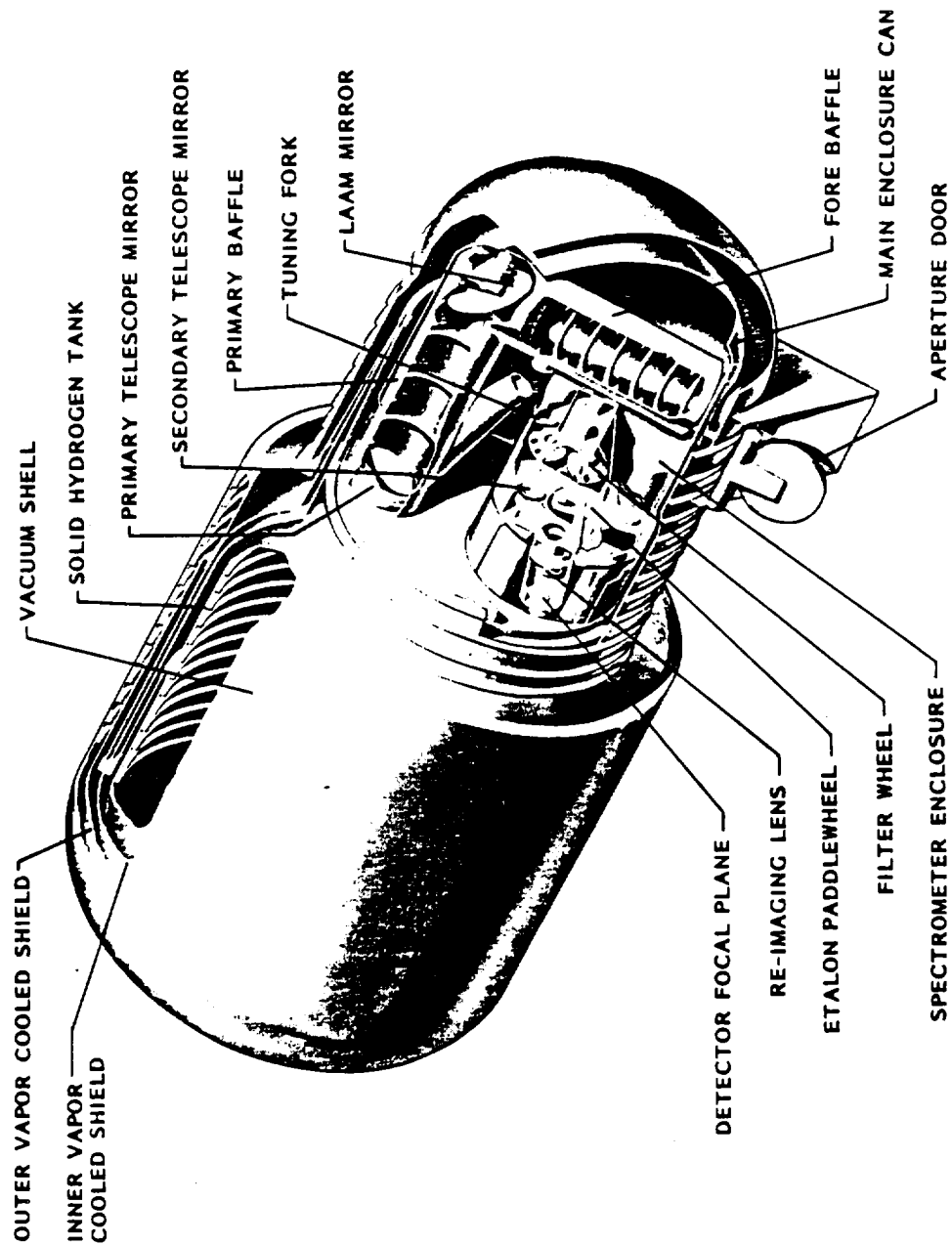
DETECTOR FOCAL PLANE

RE-IMAGING LENS

ETALON PADDLEWHEEL

FILTER WHEEL

SPECTROMETER ENCLOSURE

Table 1
CLAES Instrument Parameters

Type of measurement: Infrared thermal atmospheric emission

Type of instrument: Multiple tilting-etalon spectrometer with linear array detector

Geophysical parameters determined: Atmospheric temperature, N_2O, NO, NO_2, HNO_3, CF_2Cl_2, $CFCl_3$, HCl, O_3, $ClONO_2$, CO_2, H_2O, and CH_4

Wavelength coverage: 3.5 to 12.7 μm

Viewing geometry: Atmospheric limb, 90° to spacecraft velocity vector

- Maximum latitude sampled—80°

Comments: Detector and optics cooled by solid hydrogen cryogen, lifetime of cryogen limits operation to 18 months at 50 percent duty cycle

Spectral resolution: 0.25 1/cm and 0.32 1/cm

Vertical field of view: 50.7 km (20 elements of 2.8 km each)

Horizontal resolution: 8.4 km instantaneous footprint

- Time required to perform measurement—65 sec nominal
- Distance along spacecraft track—495 km nominal

Instrument mass: 590 kg

Average power: 22 watts

Data rate: 3 kbps

Predicted system noise equivalent radiance for CLAES is $\simeq 10^{-12}$ w/cm^2/SR at 10 μm. The instrument measures approximately 2.6 m long by 1 m diameter and weighs 590 kg when fully charged with 944 liters of H_2 cryogen.

CO-INVESTIGATORS

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IMPROVED STRATOSPHERIC AND MESOSPHERIC SOUNDER (ISAMS)

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Oxford University

INTRODUCTION

The Improved Stratospheric and Mesospheric Sounder (ISAMS) uses infrared pressure-modulator radiometry to measure thermal emission from selected atmospheric constituents at the Earth's limb. The radiance profiles obtained in this way are used to obtain nearly global coverage of the vertical distribution of temperature and composition from 80°S to 80°N.

The scientific objectives of these measurements are: (1) to determine the thermal structure of the atmosphere and its fluctuations in space and time (e.g., with season), (2) to investigate the photo-chemistry of nitrogen-containing species in the stratosphere, (3) to study the water vapor budget of the upper atmosphere. These will be addressed by measurements of carbon dioxide (CO_2) (in four bands, for temperature determination); nitrous oxide (N_2O), nitric oxide (NO), nitrogen dioxide (NO_2), nitrogen pentoxide (N_2O_5), nitric acid (HNO_3), and ozone (O_3); and water vapor, methane, and carbon monoxide.

Temperature is a fundamental atmospheric structure variable and from its measurement in four dimensions the global dynamics of the atmosphere can be inferred. Wave motions and specific phenomena such as temperature-ozone correlations and stratospheric "sudden warmings," are of particular interest. Long time series of temperature data are available and secular changes in the atmosphere are approaching the limits of detection. ISAMS will not only add to the existing data sets but will also obtain greater resolution, sensitivity, and coverage.

The reactive nitrogen species in the upper atmosphere are thought mainly to originate in the tropo-sphere as N_2O. This relatively long-lived species forms a useful tracer for some types of dynamical behavior which cannot be obtained from temperature measurements (e.g., vertical motions). The photochemical products NO, NO_2, and N_2O_5 are involved in important reactions with ozone that moderate the thermal structure and induce radiative-chemical-dynamical feedback processes that affect the behavior of the middle atmosphere. The most likely procedure for understanding these effects is the use of coupled models that are initialized using global satellite data and which predict the evolution of the NO_x fields for comparison with later measurements.

Water vapor is a particularly interesting dynamical tracer because its abundance is highly tempera-ture dependent under the conditions that prevail near the tropopause. Stratospheric water profiles contain some history of the exchange processes that brought the vapor from the troposphere. Water vapor is dissociated at very high levels, which leads to the Earth being gradually depleted of hydro-gen—there is evidence that this process has reached an advanced stage on Venus. In the stratosphere, small additional amounts of water are produced by photo-oxidation of methane. These mechanisms work together to produce an atmospheric water distribution and budget that so far has defied ex-planation, in spite of considerable attention over several decades. Water vapor is particularly impor-tant because it also contributes to radiative transfer in the upper atmosphere by its strong infrared absorption bands. In addition, it has proved to be extremely difficult to measure accurately by existing techniques. ISAMS uses a fresh approach that is expected to shed new light on the problem.

INSTRUMENT

The ISAMS instrument (Figure 1) is derived from the Stratospheric and Mesospheric Sounder (SAMS) experiment that was flown successfully on Nimbus 7 from 1978 to 1983. Both devices use pressure modulator radiometry, a technique in which samples of the gas under investigation are used to make spectral filters by modulating their pressure and hence absorption characteristics in their absorption-emission lines. This gives very high effective spectral resolution combined with relatively efficient energy throughput; the signal-to-noise ratio is further enhanced in the case of ISAMS by the use of a new design of closed-cycle Stirling refrigerators to reduce the temperature of the detectors to 80 K, approximately the temperature of liquid nitrogen.

The primary optics configuration comprises an off-axis (non-obscuring) reflecting telescope which scans the atmosphere vertically at a preprogrammed rate under microprocessor control. The instrument line of sight is nominally normal to the spacecraft flight vector but can be switched to either side of the spacecraft on command, to increase geographic coverage. An internal calibration target is provided in the primary optics and this, together with views of cold space, provides the radiometric offset and gain.

A rotating, reflecting chopper disk is located at an intermediate focal point in the optical chain and serves both to modulate the beam at several hundred hertz and to chop it against the cold space reference. The modulated beam is then modulated again by passage through the pressure modulator cells, one in each of eight channels. Two further channels contain four-position filter wheels for selecting the species that cannot be contained in modulator cells (HNO_3, N_2O_5, and O_3). Separation of the primary beam into channels is achieved using dichroic beamsplitters. The pressure modulators use coupled resonant pistons operating in antiphase; pressure amplitudes of 50 percent of the mean are achieved. Each modulator has associated with it a molecular sieve in which a quantity of the gas is stored for overall stability of the mean pressure. This also allows the mean pressure to be varied by telemetry control of the sieve temperature.

The detector in each channel is a four-element array in a square-shaped configuration. Each of the elements measures 2.6 km high by 18 km wide when projected on to the limb by the instrument optics. Each is separated from the next by a gap equal to one detector height so that contiguous profiles can be built up with a succession of steps of 2.6 km (corresponding to a 0.025° movement of the scan mirror) and 15.4 km (0.15°). To obtain signal-to-noise ratios of approximately 100:1 the instrument dwells between steps for typically 2 seconds.

The detectors are mercury cadmium telluride elements with integral converging optics; the set of eight arrays are cooled by two Stirling cycle devices via passive conductors. The coolers are pressure modulators operating on helium gas and do not have rubbing or rolling parts. This feature enables the cooler to have a long lifetime and a relatively high efficiency (about 1 watt of cooling power at 80 K for less than 80 watts power input).

All instrument functions and data processing are microprocessor controlled using programs uploaded by telemetry. Instrument parameters are shown in Table 1.
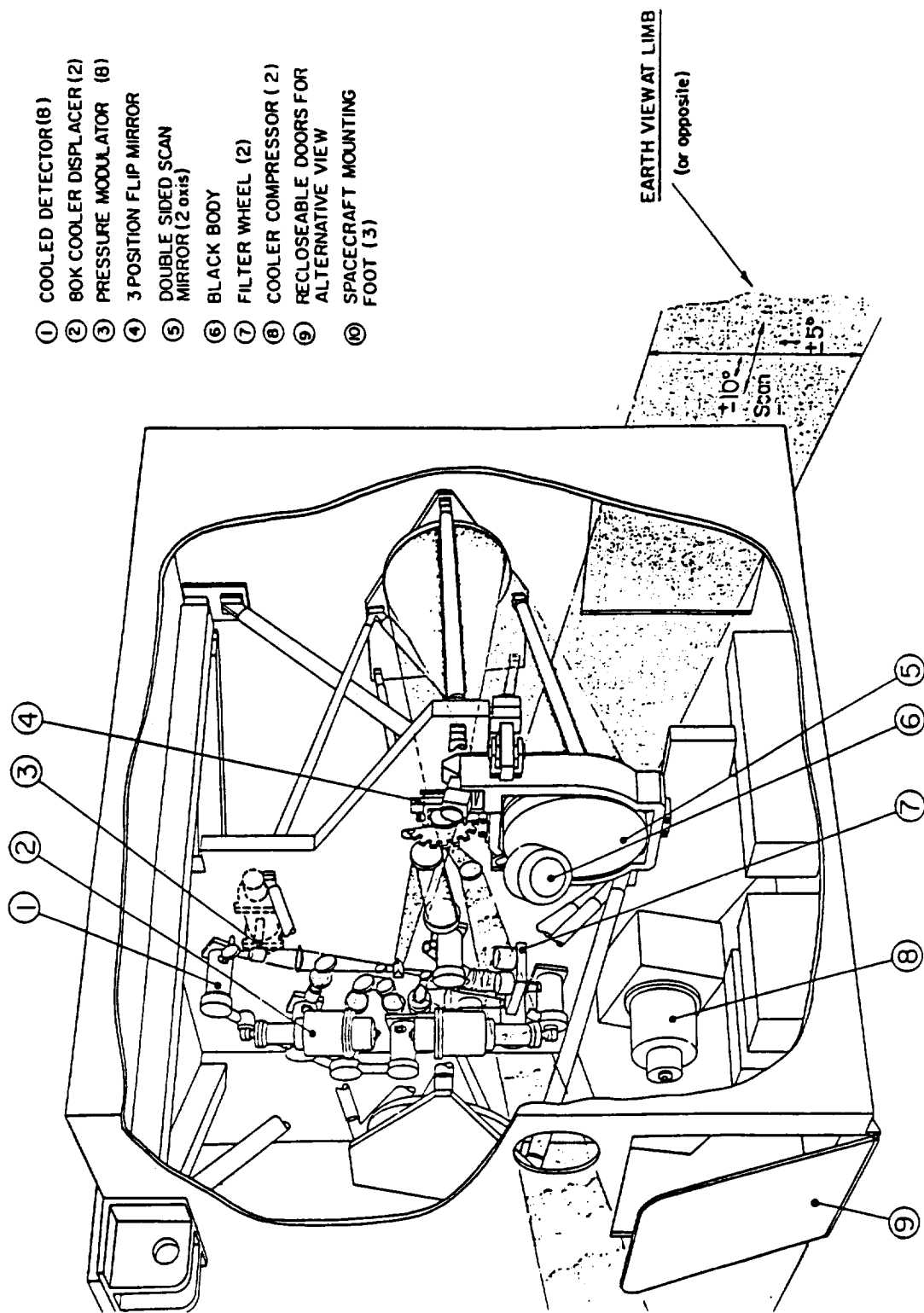
① COOLED DETECTOR(8)
② 80K COOLER DISPLACER (2)
③ PRESSURE MODULATOR (8)
④ 3 POSITION FLIP MIRROR
⑤ DOUBLE SIDED SCAN
   MIRROR (2 axis)
⑥ BLACK BODY
⑦ FILTER WHEEL (2)
⑧ COOLER COMPRESSOR (2)
⑨ RECLOSEABLE DOORS FOR
   ALTERNATIVE VIEW
⑩ SPACECRAFT MOUNTING
   FOOT (3)

EARTH VIEW AT LIMB
(or opposite)

Figure 1. Cutaway Drawing of ISAMS Sensor

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Table 1
ISAMS Instrument Parameters

Type of measurement: Infrared thermal emission

Type of instrument: Filter radiometers and pressure-modulated radiometers

Geophysical parameters determined: Temperature, CO, H_2O, CH_4, O_3, HNO_3, N_2O_5, NO, NO_2, N_2O, and aerosols

Wavelength coverage: 4.6 to 16.6 μm

Viewing geometry: 90° to spacecraft velocity

- Maximum latitude sampled: 80°

Comments: Can occasionally view toward Sun side of spacecraft

Vertical resolution: 2.6 km at limb

Horizontal resolution: 18 km at limb

- Time required to perform measurement: 16 sec for 65 km vertical scan

- Distance along spacecraft track: 121 km

Instrument mass: 172 kg

Average power: 154 watts

Data rate: 1250 bps

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MICROWAVE LIMB SOUNDER (MLS)

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INTRODUCTION

The Microwave Limb Sounder (MLS) measures atmospheric thermal emission from selected molecular spectral lines at millimeter wavelengths. From the intensity and spectral characteristics of this emission, and its variation as the MLS field of view (FOV) is scanned vertically through the atmospheric limb, profiles of geophysical parameters are inferred. Table 1 gives the frequencies of the spectral lines and the geophysical parameters to be inferred over the indicated altitude range.

Table 1
Measurement Parameters

Spectral Line Frequency (GHz)	Geophysical Parameter	Altitude Range (km)
63.0, 63.6	Pressure	30 to 60
183.3	H_2O	15 to 85
184.4	O_3	15 to 80
204.3	ClO	25 to 45
204.6	H_2O_2	30 to 40
206.1	O_3	15 to 60

Measurements are performed continuously, day and night. The instrument integration time is 2 sec, and a vertical scan is nominally performed in 1 min or less. The FOV is in a direction normal to the UARS velocity vector. Vertical resolution for all measurements except pressure is approximately 3 km. The pressure measurement, accurate to an equivalent height of 0.1 km or better, provides the atmospheric pressure level to which the other measurements apply.

The scientific objective of the MLS is to perform measurements which, together with those of the other UARS experiments, will provide a unique data base that will test and extend present understanding of the upper atmosphere. The MLS ClO measurements are essential for understanding the catalytic destruction of Earth's protective ozone layer by chlorine from industrial products. Accuracies for ClO are ~0.1 ppbv for vertical profiles obtained with 1 min time resolution, and ~0.01 ppbv for global zonal maps produced monthly. Given our present knowledge of the abundance of ClO in the stratosphere, and our lack of understanding of its variation over the globe and with time, these accuracies are exceedingly valuable. The 206.1 GHz O_3 line will simultaneously provide very

accurate ozone measurements (at least 3 percent with a goal of better than 1 percent) whose variation can be correlated with CℓO and other UARS measurements to better understand ozone chemistry. H_2O_2, which has not yet been positively detected in the atmosphere, is a difficult measurement and will require long integrations during data processing. Based on predicted H_2O_2 abundances, useful MLS measurements on a monthly basis are expected. The 183/184 GHz MLS measurements of H_2O and O_3 will be very valuable for improving our understanding of chemistry and transport in the mesosphere.

In addition to the MLS measurement objectives previously stated, secondary objectives include the measurement of height of pressure levels and the measurement of one horizontal component of wind in the upper mesosphere.

INSTRUMENT

The instrument includes three assemblies: sensor, spectrometer, and power supply. Thermal control of the sensor and spectrometer is radiational by louvers, and of the power supply by conduction to UARS.

The sensor, shown in Figure 1, includes a three-mirror antenna system that defines the FOV and a radiometer box that houses the radiometers, the multiplexing optics, and the calibration system.
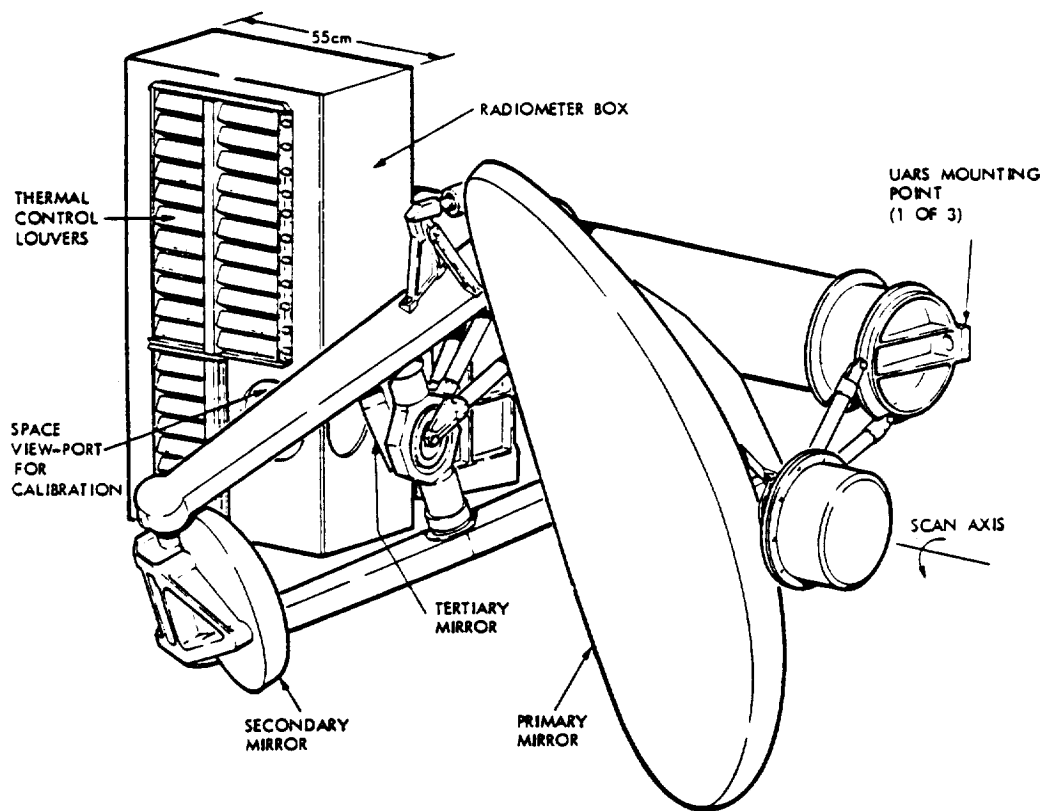

Figure 1. MLS Sensor

The angular extent of the FOV is set by diffraction limitations of the primary mirror whose 1.6 m size in the vertical plane is chosen to give ~0.05° vertical FOV extent (full width at half power points) at 205 GHz. This provides ~3 km vertical resolution for the composition measurements. The antenna system is step scanned under onboard program control. Minimum step size is 0.05° and a scan cycle including calibration, is nominally performed every "UARS minute" (65.536 sec).

A switching mirror inside the radiometer box selects either the atmospheric signal from the antenna system, the calibration from an internal target, or a zero-reference space view. The signals from the switching mirror are then spatially separated into various spectral bands by microwave optics.

Ambient-temperature Schottky-diode mixers down-convert these bands to intermediate frequencies (IF's) centered between 0.3 and 3 GHz. These IF signals are amplified by low noise amplifiers, frequency-converted again to a common center frequency of 400 MHz with 500 MHz width, and transmitted by coaxial cables to the spectrometer assembly.

The spectrometer consists of filter banks that separate the signal from each band into 15 channels. The resolution of individual channels varies from 128 MHz on the edge to 2 MHz near the center of the spectral line being measured. This resolution is matched to the characteristics of the atmospheric emission lines over the altitude range covered. A detector following each filter channel produces a voltage proportional to the power received by that channel. This voltage is then integrated, digitized to 16 bits, and read by the command and data handling system.

A microprocessor-based command and data system collects data from the various channels and the instrument engineering sensors, formats these data, and passes them to UARS. This system also receives commands and programs from UARS for controlling the MLS operation. Instrument parameters are shown in Table 2.

Table 2
MLS Instrument Parameters

Type of measurement: Microwave thermal atmospheric emission

Type of instrument: Microwave radiometer

Geophysical parameters determined: $C10$, O_3, H_2O_2, H_2O, and pressure

Frequency coverage: 63, 183, and 205 GHz

Viewing geometry: Atmospheric limb, 90° to spacecraft velocity vector
- Maximum latitude sampled: 80°

Spectral resolution: 50 MHz

Vertical FOV: 3 to 10 km at limb

Horizontal resolution:
- Field of view: 10 to 30 km at limb
- Time required of vertical scan: 65.5 sec, nominal
- Distance along spacecraft track: 495 km, nominal

Instrument mass: 290 kg

Average power: 185 watts

Data rate: 1250 bps

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HALOGEN OCCULTATION EXPERIMENT (HALOE)

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INTRODUCTION

The Halogen Occultation Experiment (HALOE) is a satellite solar occultation experiment designed to measure the global scale vertical distributions of O_3, HCℓ, HF, CH_4, H_2O, NO, and NO_2 as a function of tangent height pressure. Pressure data are inferred from absorption measurements obtained with a CO_2 channel. Latitudinal coverage for the 600 km, 57° inclined UARS orbit is from 75° S to 75° N, altitude ranges are 10 to 65 km for O_3, 10 to 55 km for CH_4, 10 to 40 km for HCℓ and HF, and 10 to 50 km for H_2O, NO, and NO_2. The vertical resolution at the horizon is 2 km in all channels with an estimated accuracy in the midstratosphere of 10 to 15 percent.

The fundamental goals of the HALOE experiment are: (1) to improve understanding of stratospheric ozone depletion due to $CℓO_x$, NO_x, and HO_x by collecting and analyzing global data on key chemical species (O_3, NO, NO_2, CH_4, HCℓ, and H_2O), (2) to provide measurements of an indicator of stratospheric chlorine content (HCℓ) as a function of altitude and to provide a means of distinguishing between chlorine produced from all sources and chlorine created from photodissociation of chlorofluoromethanes (through measurement of HF), and thus, provide information concerning anthropogenic versus natural causes of ozone destruction, and (3) to apply these data to the analysis of scientific questions and problems defined for UARS.

The specific scientific objectives of HALOE are to:

- Measure the vertical distributions of O_3, HCℓ, HF, CH_4, NO, NO_2, and H_2O and prepare a global climatology for these species.

- Compare vertical, geographical, and seasonal variations measured by HALOE with measurements by the SAGE experiment on AEM, and the LIMS, SAMS, and SBUV experiments on Nimbus 7.

- Establish the global distribution and budgets of ozone, source molecules (CH_4 and H_2O), reservoir molecules (HCℓ and HF), NO, NO_2 and other species. Studies have shown that given the data provided by the eight HALOE channels, the concentrations of most of the other gases of interest can be calculated using photochemical relationships. Data from other UARS experiments (e.g., CℓO, $CℓONO_2$, $CF_2Cℓ_2$, and $CFCℓ_3$ from CLAES and MLS) will be used to verify these calculations.

- Use measured vertical profiles of O_3, HCℓ, HF, and NO to study the response of the upper atmosphere to perturbations, especially solar UV variability, solar proton events, and volcanic eruptions.

- Analyze the measured data and conduct scientific investigations related to global ozone depletion, chlorine sources and sinks, seasonal and long term changes in gas concentrations (e.g., HCℓ and HF), stratospheric dispersion processes, and latitudinal and longitudinal variability of various species.

- Use the measured data to support refinements of multidimensional chemical and dynamics models.

The HALOE objectives will be achieved by measuring the absorption of solar energy by gaseous constituents as a function of tangent height pressure during Sunrise and Sunset (Figure 1). A vertical scan of the stratosphere is obtained by tracking the Sun position during occultation. Temperature affects on the retrieval of gas concentration are second order and will be included by using climatological data. Data from the NOAA meteorological analysis and other satellite measurements will also be used when available.

INSTRUMENT

The HALOE instrument uses the gas-filter-correlation radiometer technique for measurement of HCℓ, HF, CH_4, and NO, and broadband spectroscopy for measurement of O_3, H_2O, NO_2, and tangent height pressure (CO_2). The principle of gas-filter-correlation radiometry is illustrated schematically in Figure 2. Solar energy enters the sensor and is divided into two paths. The first path contains a cell filled with the gas to be measured (e.g., HCℓ, HF, NO, CH_4), the second is a vacuum path. An electronic gain adjustment is used in one detector circuit. This adjusts the signal output so that the two electro-optical paths are matched when there is no target gas in the intervening atmosphere (i.e., "balanced" outside the atmosphere). When the target gas is present in the atmosphere, a spectral content is introduced to the incoming energy which is correlated with the absorption line spectrum in the gas cell. This correlation upsets the matched condition, causing a signal difference that is proportional to stratospheric HCℓ, HF, NO, or CH_4 concentration. To minimize the sensitivity of the HCℓ measurement to interfering CH_4 absorption, a CH_4 attenuation cell is included in front of both the vacuum and the gas cell paths. The radiometer channel data are reduced by ratioing occultation data and data taken outside the atmosphere to obtain atmospheric transmission. The transmission is then used to retrieve mixing ratio as a function of pressure.
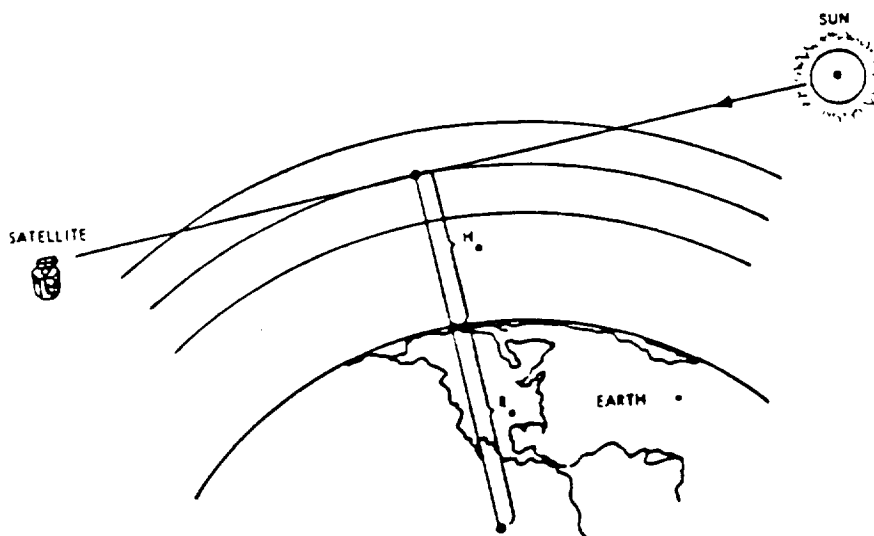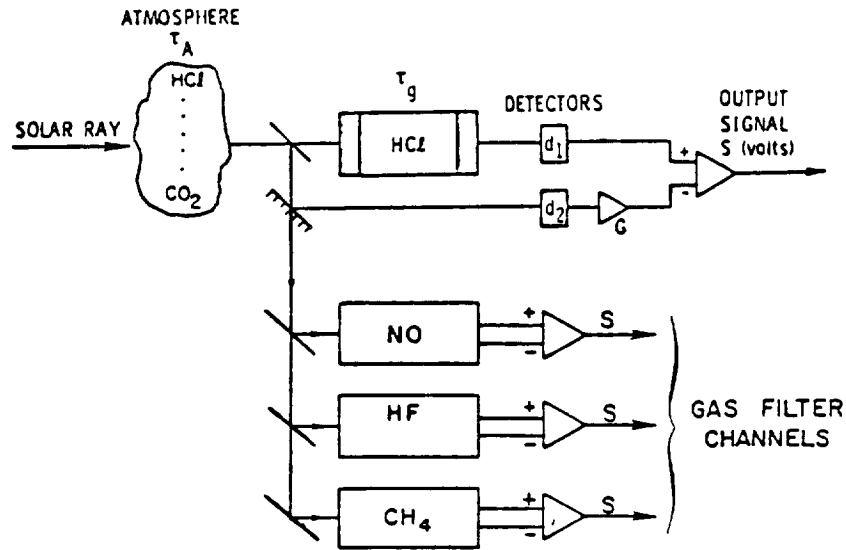

Figure 1. Experiment Geometry

Figure 2. HALOE Gas Filter Correlation Technique

The HALOE instrument (Figure 3) consists of an optics unit supported on a two-axis gimbal and an off-gimbal electronics unit. The optics unit contains the optics, modulators, detectors, and preamps for all gas detection channels. A 16-cm diameter reflective Cassegrain telescope collects solar energy for all channels and a field stop at the focal point of the telescope determines the instantaneous field of view of the instrument. The incoming solar energy is chopped at 150 Hz by means of a reflective chopper: reflected energy is directed to the radiometer channels and nonreflected energy is directed to the gas filter channels. A second optical signal from a blackbody reference is chopped at 300 Hz to maintain the exo-atmospheric gain balance in the gas filter channels during the occultation event. After passing through the chopper the nonreflected optical beam is separated by beam splitters into the four gas filter channels. The processed signals from these channels together with the processed signals from the radiometer channels are inverted to provide the gas concentration data for each event.

A stepper-driven calibration wheel is located behind the telescope field stop to provide periodic measurements of gas response, radiometric calibration, and instrument balance, using the exo-atmospheric Sun as an energy source. The calibration wheel contains eight gas cells and three neutral density filters for in-flight scale factor and linearity calibration checks.

The gimbal assembly is a stepper-driven, two-axis (azimuth and elevation) biaxial assembly that supports the optics unit near the center of gravity of the instrument. The gimbals provide a capability for fine tracking. Tracking control signals for the gimbals are derived from the Sun sensors which have their own optics and electronics systems.

The off-gimbal electronics unit provides signal processing, motor drives, sequence timing, mode control, power conditioning, and data handling. This unit is the major electrical interface between the spacecraft and the HALOE instrument. Instrument parameters are shown in Table 1.
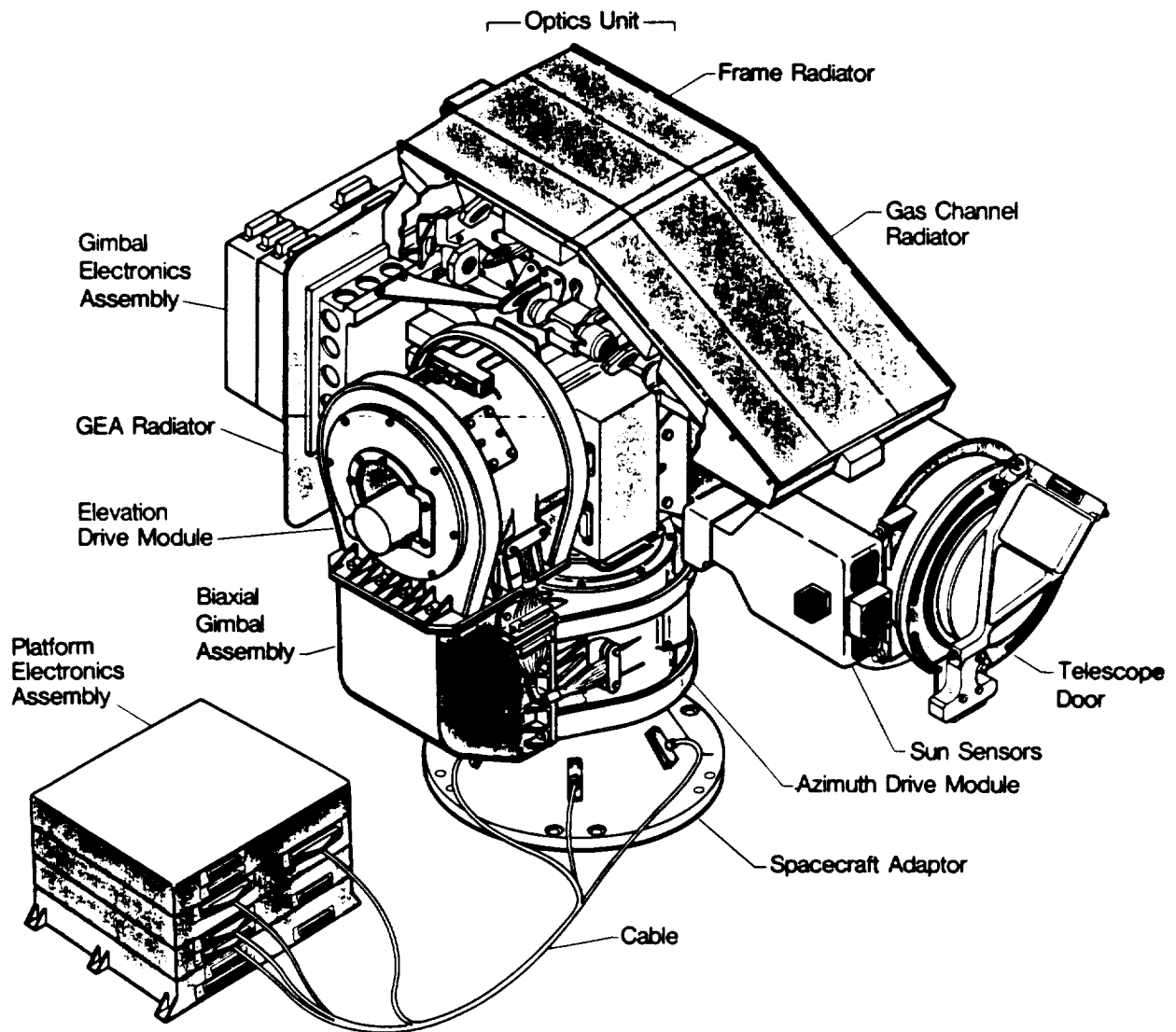
Figure 3. HALOE Instrument Concept

Table 1
HALOE Instrument Parameters

Type of measurement: Solar occultation, infrared atmospheric absorption

Type of instrument: Gas correlation and filter radiometers

Geophysical parameters determined: HF, HC1, CH_4, NO, CO_2, H_2O, O_3, NO_2, and pressure

Wavelength coverage: 2.43 to 10.25 μm

Viewing geometry: Spacecraft sunrise and sunset

Spectral resolution: 20 to 120 1/cm

Vertical resolution: 2 km at limb

Horizontal resolution: 6.2 km at limb

Instrument mass: 111.7 kg

Average power: 110 watts

Data rate: 4000 bps

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3.3 WINDS

- High Resolution Doppler Imager, P. B. Hays, University of Michigan

- Wind Imaging Interferometer, G. G. Shepherd, York University, Toronto, Canada

- Active Cavity Radiometer Irradiance Monitor, Richard C. Willson, Jet Propulsion Laboratory

HIGH RESOLUTION DOPPLER IMAGER (HRDI)

P. B. Hays
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INTRODUCTION

A High Resolution Doppler Imager (HRDI), is being designed and fabricated at the University of Michigan, Space Physics Research Laboratory to study the dynamics of the Earth's atmosphere from the Upper Atmosphere Research Satellite. The instrument is a triple etalon Fabry-Perot interferometer that views the Earth's atmosphere through a two-axis gimbal telescope from the spacecraft altitude of 600 km.

The output of the interferometer is horizontal vector wind fields with an accuracy exceeding 5 meters per second over prescribed regions of the atmosphere extending from the upper troposphere through the thermosphere. These data will be used in a comprehensive study of the dynamics of the atmosphere and the dynamic coupling between the various regions of the atmosphere.

The measurements will be made with a stable, triple etalon high resolution Fabry-Perot interferometer, which performs wavelength analysis on the light detected from atmospheric emission or absorption features by spatially scanning the interference fringe plane with a multichannel array detector. A sequential altitude scan performed by the commandable telescope provides global coverage of the thermodynamic and dynamic state of the atmosphere from cloud top through the thermosphere.

INSTRUMENT

The HRDI instrument consists of several subsystems as shown in Figure 1: (1) two-axis gimbal telescope, (2) triple etalon Fabry-Perot interferometer and interferometer electronics, and (3) support electronics and dedicated experiment processor.

The telescope subassembly consists of a well baffled off-axis parabola telescope mounted on a two-axis gimbal structure. This provides the capability of pointing anywhere within a two-pi hemisphere, relative to the mounting base, so that look angle requirements to measure wind vectors at various altitudes is achieved.

An optical bench supported by kinematic mounts, interferometer optics (Figure 2), and support electronics make up the interferometer subassembly. Optical elements include:

- A fiber optic provides input from the telescope subassembly.

- Two, eight-position filter wheels provide spectral resolution for preselected regions of interest.
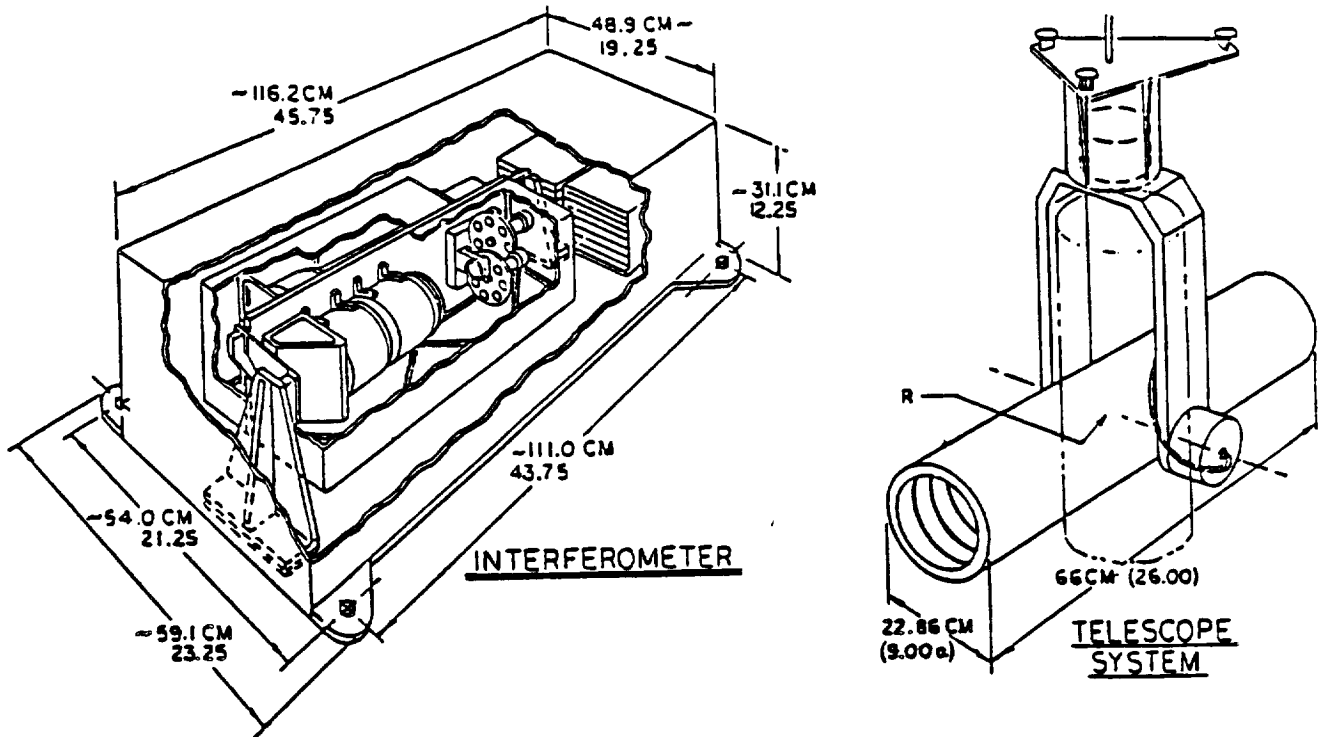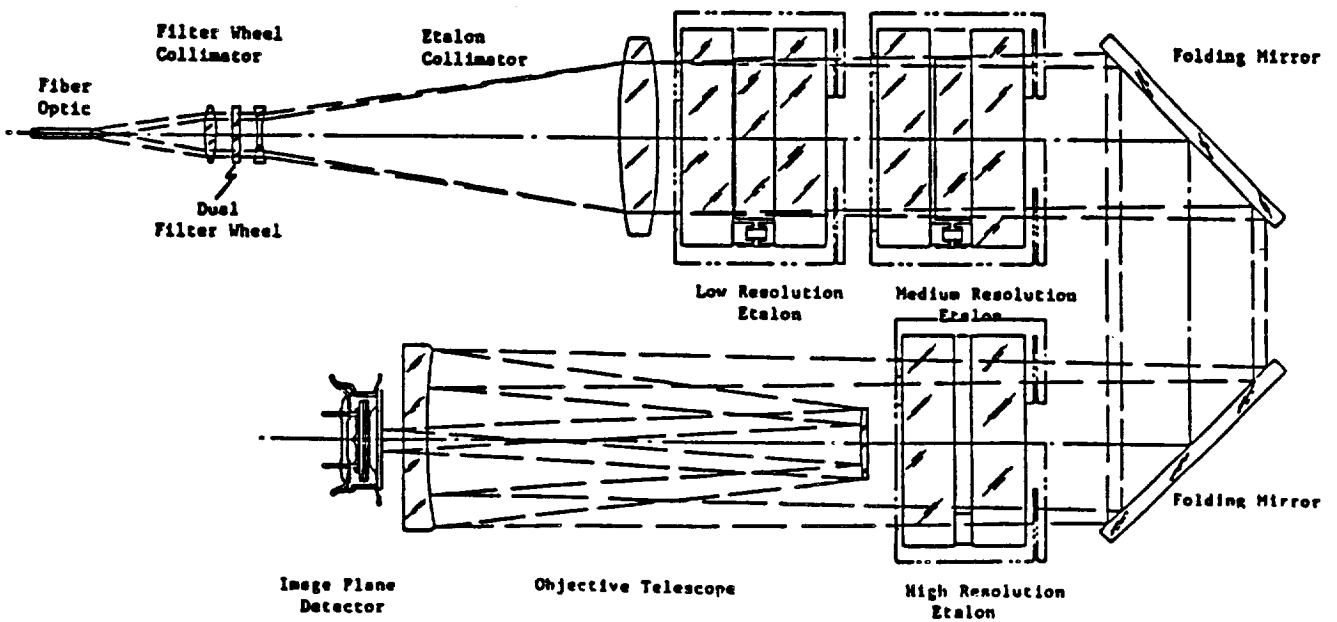
Figure 1. HRDI Subsystems

Figure 2. Interferometer Optics

- A multiple etalon Fabry-Perot is used, because absorption features appear in a continuum and white light rejection is required. These requirements, and the need for high throughput, have led to the development of a triple etalon Fabry-Perot interferometer as the spectral filtering device.

- The low resolution etalon and medium resolution etalon are of particular interest in that they use piezoelectric spacers to tune gap spacing in response to feedback circuit commanded by the dedicated experiment processor. Etalons for the interferometer are 132 mm in diameter with 90 mm clear field of view.

- The folding mirrors are used to reduce overall length of the instrument thereby reducing size, weight, and packaging requirements.

- The objective telescope for the interferometer will be a ruggedized Questar telescope, which focuses interference patterns received from the high resolution etalon onto the image plane detector.

- The image plane detector, developed by the University of Michigan and ITT Electro Optics Division, is a modification of the design flown on the Dynamics Explorer Satellite. This 32 element concentric ring anode converts the ring pattern of photons produced by the etalons into a set of discrete electron pulses.

Other electronic systems support interferometer requirements including power supply, telemetry, and logic and command. The dedicated experiment processor is a microcomputer used to control instrument functions including telescope position, filter selection mechanism, and etalon control.

Table 1
HRDI Instrument Parameters

Type of measurement: Doppler shift and line broadening of scattered sunlight and atmospheric emission in the visible

Type of instrument: Fabry-Perot interferometer

Geophysical parameters determined: Horizontal vector wind and atmospheric temperature

Wavelength coverage: 400 to 800 nm

Viewing geometry: 45° and 135° to spacecraft velocity vector

- Maximum latitude sampled: 74°

Comments: Gimbled telescope provides potential for viewing any azimuthal direction; orthogonal measurements for same atmospheric volume separated by approximately 8 minutes

Spectral resolution: 0.001 nm (0.01 Å)

Vertical resolution: 4 km at limb (0.05° field of view)

Horizontal resolution: 128 km at limb (1.6° field of view)

- Time required for one vertical scan: 7.33 sec for 90 km scan
- Distance along spacecraft track: 55 km per scan
- Potential of four vertical scans of vector wind in 500 km along track

Instrument mass: 83.8 kg

Average power: 82 watts

Data rate: 4500 bps

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WIND IMAGING INTERFEROMETER (WINDII)

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INTRODUCTION

The Wind Imaging Interferometer (WINDII) senses temperatures and winds in the upper atmosphere by measuring the Doppler widths and shifts of isolated spectral lines emitted by the airglow and aurora in the mesosphere and the lower thermosphere. This is a region of complex dynamics, where atomic oxygen is generated, where upward propagating gravity waves become important, and where the transition from a mixed atmosphere to the region of diffusive equilibrium occurs.

The instrument views the atmospheric limb simultaneously in two directions, 45° and 135° from the velocity vector; due to the spacecraft motion, these cover the same atmospheric region with a time delay of a few minutes. This provides both horizontal components of the neutral wind. An imaging detector provides simultaneous measurements of temperature and wind profiles over an altitude range of 70 to 310 km. The detector also permits the observation of wave-like structures having scale sizes down to 3 km. A variety of emission lines is available to cover the desired altitude range: OI 557.7 nm and 630.0 nm, two OH lines, a line in the O_2 atmospheric band at 762.0 nm, and an O^+ line at 732.0 nm. With these emissions, the altitude range can be covered for both day-time and nighttime.

INSTRUMENT

The instrument consists essentially of a CCD camera viewing the Earth limb through a field-widened Michelson interferometer. Four images are taken, with the interferometer optical path difference changed by $\lambda/4$ between images. From these images, fringe phase (leading to wind velocity), fringe modulation depth (leading to temperature), and emission rate are determined. A field combiner in the input optics accepts the two orthogonal fields of view, and locates them side by side on the CCD so that both views are simultaneously recorded.

The Michelson optics are a solid assembly comprising a cemented glass hexagonal beamsplitter, a glass block with a deposited mirror in one arm of the interferometer, and a glass block combined with an air gap and a piezoelectrically driven mirror in the other arm. The mirror position is controlled through capacitive sensing to provide stability and stepsize of the required accuracy. The glass arm lengths and the air gap size are chosen to provide achromatic field widening, and a responsivity of optical path difference to temperature that is very small and achromatic. The optics are contained in a thermal enclosure that provides mechanical support and removes thermal gradients. The configuration is shown as part of Figure 1.

The CCD camera consists of a fast camera lens and an RCA 501E CCD cooled to -50°C. The imaging area comprises 320 by 256 pixels, and has a corresponding storage area that the image is shifted into after the exposure. During readout, binning and windowing are employed to select desired altitude ranges, and to tailor the image to the available telemetry rate.
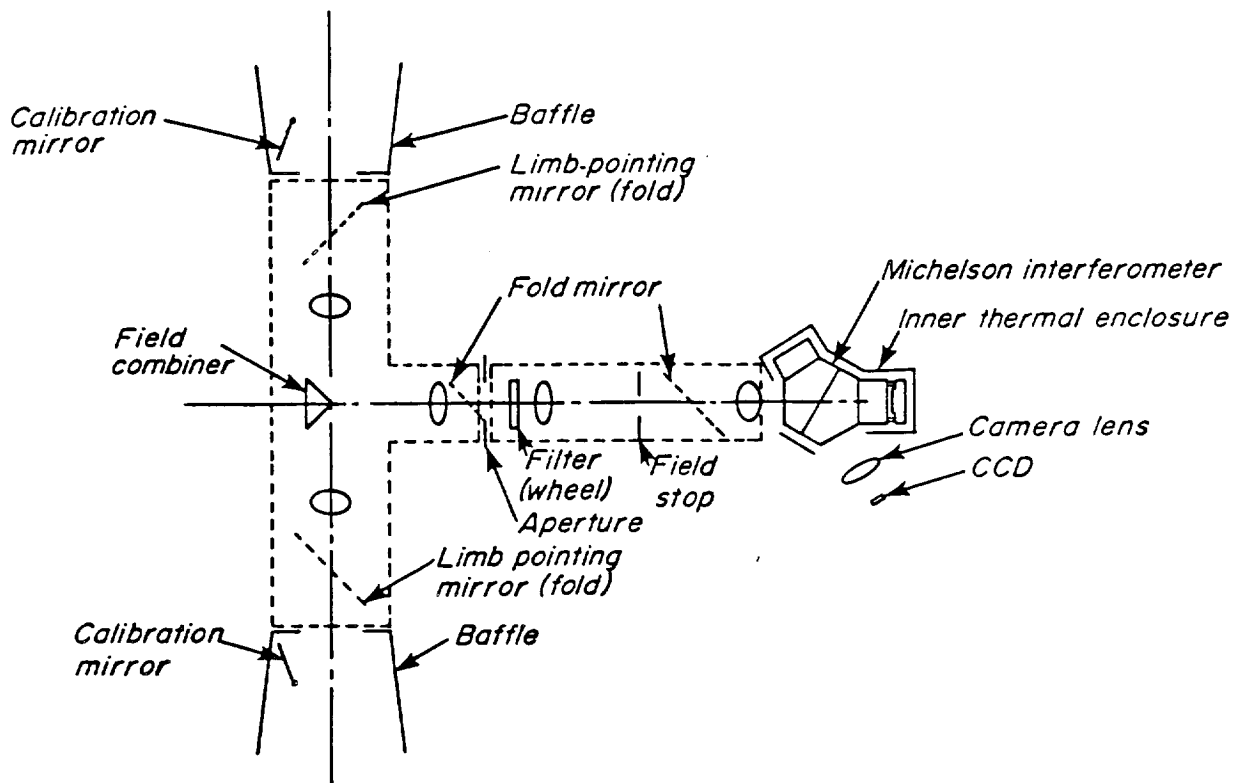
Figure 1. WINDII Optical Schematic

To isolate specific spectral lines, interference filters are mounted in a temperature-controlled filter wheel assembly. For most emissions, bandwidths of about 1 nm are adequate, but for the O_2 atmospheric band a low-resolution Fabry-Perot etalon is also required. This forms interference rings on the CCD, which limits the useful data to the regions falling within the rings. The regions between the rings, however, give a precise measurement of background contamination that is particularly useful for daytime measurements.

A double telescopic input is required to generate accessible aperture and field stops, to eliminate stray light, to transform the field of view to the desired value, and to provide a suitable location for the beam combiner. A schematic diagram of the optical layout is shown in Figure 1. This optical train contains the filter wheel, a mirror for calibration sources, and an aperture stop-down to provide lower scattered light levels for daytime viewing. A one-meter long baffle tube is used in each input. These baffles are made intersecting to fit within the available space. A mechanical layout is shown in Figure 2.

A separate calibration box is provided, containing radio frequency excited spectral lamps, a tungsten lamp, and a He-Ne laser. The spectral lamps are used for frequent phase calibration, and the tungsten lamp and laser are used for infrequent responsivity and visibility calibrations, respectively.

An internal microprocessor controls all the instrument functions such as camera control, filter wheel control, thermal control, and control of all mechanisms. Buffer memory exists for the image data so that additional onboard processing can be performed before data are routed to telemetry.

Baffles

Limb-pointing mirror

Michelson interferometer

CCD camera
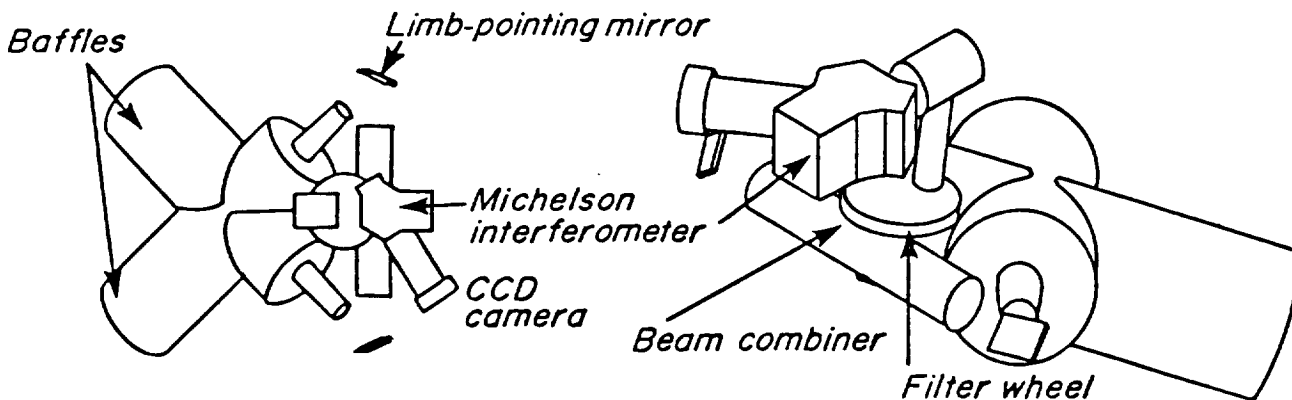
Beam combiner

Filter wheel

Figure 2. WINDII Mechanical Configuration

Table 1
WINDII Instrument Parameters

Type of measurement: Doppler shift and line broadening of atmospheric emission in the visible and near infrared

Type of instrument: Field-widened Michelson interferometer

Geophysical parameters determined: Atmospheric temperature and horizontal wind vector

Wavelength coverage: 550 to 780 nm

Viewing geometry: 45° and 135° to spacecraft velocity vector

- Maximum latitude sampled: 74°

Comments: Orthogonal measurements for same atmospheric volume separated in time by approximately 8 minutes

Vertical field of view: 6°, 70 to 310 km at horizon

Vertical resolution: 4 km at horizon (nominal)
1.5 km at horizon (potential)

Horizontal resolution: 20 km (along track) at horizon

- Time required to perform measurement: 8 sec
- Distance along spacecraft track: 60.5 km

Instrument mass: 110 kg

Average power: 85 watts

Data rate: 2000 bps

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ACTIVE CAVITY RADIOMETER IRRADIANCE MONITOR (ACRIM II)

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INTRODUCTION

The objective of the Upper Atmosphere Research Satellite/Active Cavity Radiometer Irradiance Monitor (UARS/ACRIM II) Experiment is to conduct precise solar total irradiance monitoring during a period of expected increasing solar activity approaching the maximum for solar cycle 22, in support of climatological and solar physics investigations. The UARS/ACRIM II instrument will be an important component of the long term solar irradiance monitoring "principal thrust" of the National Climate Program, which proposes to study solar irradiance variability and its weather/climate significance over at least one solar magnetic cycle, about 22 years. The UARS/ACRIM II results will provide for the continuity of precise tracking of solar activity/solar irradiance output relationships that have been highly productive during the measurement period of the Solar Maximum Mission (SMM) ACRIM I in increasing our understanding of basic stellar phenomena.

The ACRIM II is expected to overlap the extended ACRIM I on the SMM which has monitored continuously the total solar irradiance since its launch in February 1980. The ACRIM I results have provided cornerstone observations for the National Climate Program's solar total irradiance monitoring requirement. ACRIM II will provide another important segment of the climate/solar physics solar irradiance data base begun by ACRIM I.

The ACRIM II is designed for the continuous measurement of solar total irradiance with uniform sensitivity from the far ultraviolet (UV) to the far infrared (IR) wavelength range with an "absolute" uncertainty in the International System of Units (SI) of ±0.1 percent, a single sample resolution of 0.012 percent, and a multiyear internal precision of ±5 ppm. The UARS/ACRIM II instrument, like its predecessor ACRIM I, will use three ACR pyrheliometers that are the more advanced type V design developed for the Spacelab 1/ACR (SL1/ACR). Use of the three redundant ACR detectors with different operating frequencies provides long term precision through in-flight self calibration of sensor degradation.

CLIMATE

During the last decade, the development of increasingly sophisticated climate models has produced a corresponding increase in their sensitivity to various boundary conditions including the most important one—the total solar irradiance of the Earth. The threshold of model sensitivity for irradiance variations has decreased to 0.1 percent. Attempts to test the modeled climates against the historical solar irradiance record found the preACRIM I irradiance record to be inadequate. These factors, with the discovery of past climate cycles associated with solar magnetic activity, combined to provide the impetus for defining solar irradiance monitoring as a major component of the solar and Earth radiation "principal thrust" in the National Climate Program. The experimental requirements were the measurement of total solar irradiance with a precision of 0.1 percent or better over a period of at least one complete cycle of solar magnetic activity.

SOLAR PHYSICS

One of the major discoveries of the ACRIM I was solar total irradiance variability on time scales of days to months. These variations were the result of modulation of the average solar irradiance by sunspots and faculae in active regions. Sunspots, which have temperatures lower than the average photosphere, are capable of producing temporary irradiance deficits of up to 0.25 percent. Faculae with above average temperatures, cause radiative excesses and may be responsible for restoring energy equilibrium in solar active regions. The ACRIM II will provide additional data for exploring irradiance/solar activity relationships.

Solar global oscillations in both the pressure and gravity modes have been detected in the irradiance measurements of ACRIM I. These observations facilitate helio-seismological analyses that can lead to increased understanding of the physics of the deep solar interior. The ACRIM II results, which are even more precise, will add considerably to this discipline.

MEASUREMENT IMPLEMENTATION

The climatological requirement for a solar total irradiance record with 0.1 percent precision over decades makes severe demands on the current state of the art in solar pyrheliometry. The only approach guaranteed capable of sustaining this level of precision would be the deployment of over-lapping, successive satellite solar monitoring experiments whose observations could be related at their level of mutual precision. Nonoverlapping experiments would have to be related through other, intermediary measurements or through their absolute calibrations. In the latter case, the ±0.1 per-cent SI uncertainty of present solar pyrheliometry would place a lower limit of ±0.2 percent on the precision with which the results of any two successive solar monitors could be related. Because the solar record over one solar magnetic cycle of 22 years may be constructed from the results of many experiments, the absolute calibration approach will not be adequate.

It is not clear that the optimum approach of deploying overlapping satellite solar monitoring experi-ments can be accomplished during the 1980's. Continued operation by the ACRIM I until then would require a discomforting amount of good luck. An alternative measurement strategy is required to provide guaranteed relativity between SMM/ACRIM I and UARS/ACRIM II with climatologically useful precision.

Accordingly, the NASA solar monitoring program is comprised of a combination of satellite solar monitors and shorter annual solar irradiance flight experiments on rockets, balloons (1976 to 1986), and the Space Shuttle (1983 to 1993). The ACRIM satellite monitors provide a solar variability record with the sampling frequency required by climate and solar physics. The short term irradiance experiments have a dual role to provide independent calibrations of the degradation of individual satellite monitors and to serve as intermediary control experiments, linking successive satellite experi-ments if one should fail before the next is deployed. If ACRIM I fails before deployment of ACRIM II, the rocket and shuttle experiments, through direct flight comparisons with both, will have an important role in minimizing the uncertainty of relating the ACRIM I and II results. The long term uncertainty of the solar variability record, sustained by intermediate experiments, will not equal the level that can be achieved through overlapping deployment of satellite solar monitors, but it will certainly be better than the absolute calibration approach could provide.

INSTRUMENT SUMMARY

Basic ACRIM II instrument parameters are shown in Table 1. The conceptual drawing of the ACRIM II for the UARS is shown in Figure 1.

Table 1
ACRIM II Instrument Parameters

Description: Active Cavity Radiometer Irradiance Monitor II

Sensors: Three type V Active Cavity Radiometers for total irradiance monitoring, one Sun position sensor

Accuracy: 99.9 percent at solar total irradiance level

Precision: ±0.012 percent of full scale for single samples. Phased operation of sensors for stand-alone calibration of degradation yields precision better than ±0.005 percent over 1 year periods.

Ranges:

- Total irradiance—0 to 2000 W/m^2
- Wavelength—0.001 to 1000 micrometers

Field of view: ±5° with ±1° tolerance for solar pointing

Sun position: Measures instrument solar alignment to ±5° with ±0.1° resolution

Data rate: 500 bps

Power: 10 watts

Weight: 26 kg

SHUTTER MODULE

J22 TEST POINTS

SHUTTER DRIVE AND
POSITION SENSING
ELECTRONICS

ALIGNMENT CUBE
(COVERED)

DIGITAL ELECTRONICS

J21 TEST POINTS

ANALOG ELECTRONICS

SENSOR ASSY

POWER SUPPLY
ELECTRONICS

INTERFACE
ELECTRONICS

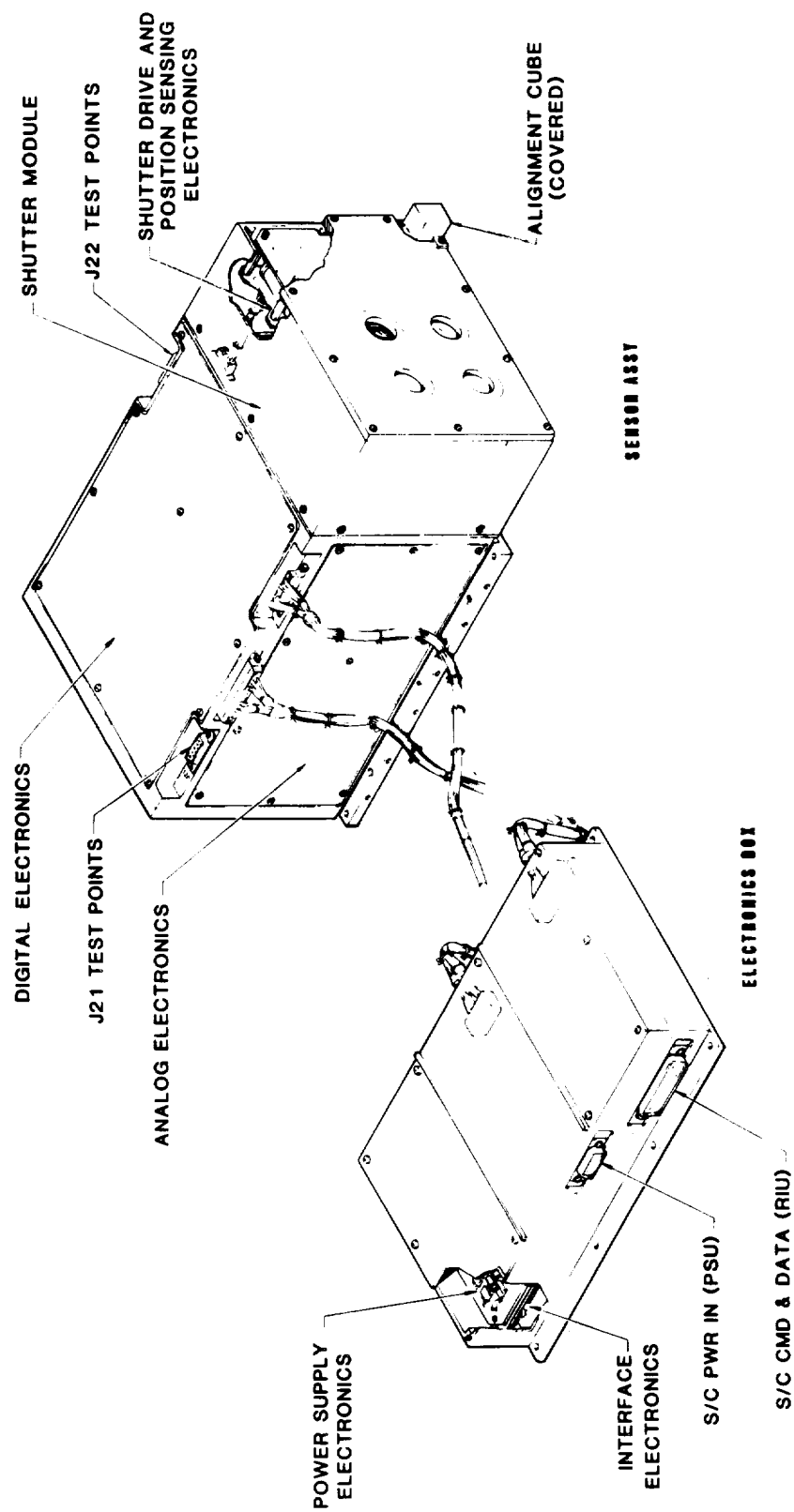S/C PWR IN (PSU)

S/C CMD & DATA (RIU)

ELECTRONICS BOX

Figure 1. Active Cavity Radiometer Irradiance Monitor (ACRIM II)

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